ADA

SINGLE COMMON POWERTRAIN LUBRICANT (SCPL) DEVELOPMENT (PART 3)

INTERIM REPORT
TFLRF No. 462

by
Adam C. Brandt
Edwin A. Frame

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Mr. Allen S. Comfort
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD20 & WD21)

UNCLASSIFIED: Distribution Statement A. Approved for public release

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14. ABSTRACT
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Single Common Powertrain Lubricant (SCPL), Detroit Diesel Corporation (DDC) 6V53T, High Temperature Oil Endurance, MIL-PRF-46167, MIL-PRF-2104, Total Acid Number (TAN), Total Base Number (TBN), Wear Metals, Oxidation, Fuel Economy, Pumping Losses, Transmission, Caterpillar TO-4, Allison C4, Mack T-12

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EXECUTIVE SUMMARY

The objective of this project was to continue validation testing of two SCPL candidates that have been further revised for improved performance based upon previously attained results during SCPL Development Parts 1 and 2. This report discusses results for: chemical and physical bench testing, transmission application frictional testing, high temperature 2-cycle diesel engine compatibility, and Mack T-12 wear performance testing.

All testing shows that the revised SCPL candidates still have areas where they can be improved upon in industry standardized tests. However, all testing in military applications apart from high temperature two cycle diesel engines has shown positive results. The following conclusions can be made from these final test areas reported:

- Bench top analytical testing showed revised candidates exceed industry standards for high temperature bearing corrosion, foaming resistance, and elastomer compatibility.

- SCPL candidates still show borderline failures in some of the standardized transmission testing, but as previously analyzed, failures occurring are not expected to cause compatibility issues in military equipment due to the minimal excursions past the frictional limit lines in testing. All applied transmission testing conducted in the RAM-D Stryker testing and field demonstrations has shown that transmission function remains acceptable while using the SCPL.

- Use of the SCPL in high temperature two cycle diesel engines is not advisable. The critical piston/liner architecture in two cycle diesel engines does not tolerate low viscosity and increased operating temperatures, and results in uncontrolled liner scuffing.

- Results from standardized Mack T-12 test were varied. Neither SCPL candidate met the CJ-4 accreditation level, but test results are questionable based on industry wide consistency issues within the test.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period of September 2012 through February 2015 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler (RDTA-SIE-ES-FPT) served as the TARDEC contracting officer's technical representative. Mr. Allen Comfort of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical support staff and administrative support staff.

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ACRONYMS AND ABBREVIATIONS

6V53T – 6 cylinder, v-configuration, 53 cubic inches per cylinder, turbocharged diesel engine

ASTM - American Society of Testing and Materials

BDC – bottom dead center

DDC – Detroit Diesel Corporation

EGR – exhaust gas recirculation

F/B – front/back direction

FRRET – friction retention

FTM – federal test method

GOCO – government owned, contractor operated

HTCBT – High Temperature Corrosive Bearing Test

MIL - military

MIL-PRF – military performance

RAM-D – reliability, availability, maintainability, and durability

SCPL – Single Common Powertrain Lubricant

SOW – statement/scope of work

SwRI – Southwest Research Institute

T/AT – thrust/anti thrust direction

TARDEC – Tank Automotive Research Development and Engineering Center

TFLRF – TARDEC Fuels and Lubricants Research Facility

ULSD – ultra low sulfur diesel fuel

1.0 INTRODUCTION & BACKGROUND

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 products are currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic to high temperature desert conditions, representative of the wide range of potential military operating conditions. In addition, the SCPL must meet or exceed performance currently attained by approved MIL specification products. By achieving these goals, multiple lubricant specifications could be reduced into a single specified product that could be used in tactical and combat vehicles in any seasonal or geographical location. The development of this lubricant has the potential to reduce the logistical burden on the military's supply chain, reduce operating costs, and improve lubricant performance beyond current fielded products.

Due to the extreme application requirements and performance goals, it is probable that the SCPL be formulated from synthetic basestocks. To offset the increased price of synthetic basestocks, several performance goals must be met by the SCPL, such as increased vehicle fuel efficiency and extended drain intervals. Research has shown that there is a potential reduction in fuel consumption through the use of low viscosity lubricating fluids [1,2]. This change in fuel consumption is attributed to the reduction in mechanical losses within the system. These mechanical losses can be related to frictional properties, pumping efficiencies, and overall bulk churning in mechanical applications. Although reductions in fuel consumption through viscosity changes are expected to be relatively small (1-2%), when incrementally multiplied over a large group of vehicles such as the military's combat and tactical fleet, fuel savings and thus cost savings can be substantial. This drive for viscosity reduction as a means of efficiency increase complements the SCPL’s requirement to provide extreme cold climate performance, as low fluid viscosities are required to ensure low temperature pumpability than typical heavy duty diesel oils. Synthetic basestocks also typically offer an increased resistance to oil degradation, which allows the extension drain interval times, resulting in reduced required maintenance. This extension of service intervals, combined with the increased efficiency through lowered viscosity help offset costs associated with the use of synthetic basestocks over typical petroleum basestocks [3,4,5].

This report is the third and final in a series covering the SCPL development, and focuses on the final refinement and primarily industry standardized testing of two initial SCPL candidates identified during research reported in TFLRF Interim Report 418, Single Common Powertrain Lubricant (SCPL) Development (hereinafter referred to as Part 1) [4], and TFLRF Interim Report 442, Single Common Powertrain lubricant (SCPL) Development Part 2 (hereinafter referred to as Part 2) [5]. All testing reported was completed at the government owned, contractor operated (GOCO) U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF), located at Southwest Research Institute (SwRI) in San Antonio, Texas. Performance investigations reported include: bench testing to analyze candidate physical properties, transmission application frictional testing, high temperature 2-cycle diesel engine compatibility using the Detroit Diesel Corporation (DDC) 6V53T, and American Society for Testing and Materials (ASTM) D7422 Mack T-12 wear performance testing.

2.0 OBJECTIVE & APPROACH

The overall objective of this project was to continue validation testing, in primarily industry standardized testing, of two SCPL candidates that have been further revised for improved performance based off of previously attained results during SCPL development Part 1 and Part 2. This data would reinforce the previously feasibility studies [6,7,8], preliminary development efforts in SCPL development Part 1 and Part 2, and verify final candidate advancement towards the goals of the SCPL.

3.0 DISCUSSION OF RESULTS

The following sections discuss latest SCPL candidate results for: chemical and physical bench testing, transmission application frictional testing, high temperature 2-cycle diesel engine compatibility, and Mack T-12 wear performance testing.

3.1 Chemical & Physical Property Bench Testing

Table 1 shows the chemical and physical property analysis of the latest candidate revisions compared to the versions tested during SCPL development Part 1 and Part 2. As shown, the latest revision of candidate B has improved the low temperature viscosity at -48 °C, and also has reduced NOACK volatility. These were both desired improvement from the Part 2 candidate analysis. Candidate A appears to be similar overall to its previous versions, with its most notable change being seen as increased low temperature viscosity.

Table 1. Chemical and Physical Property Analysis

Method	Temp	Property	Units	Initial Candidates (Part 1)		Revised Candidates (Part 2)		Revised Candidates (Part 3)	
				a	b	a	b	a	b
				LO253071	LO251746	LO268869	LO271510*	LO306520	LO292039
D445	-40°C	Viscosity	cSt	7661.6	11158	14798.2	12885.34	15353.02	13254.19
D445	100°C	High Temp Viscosity	cSt	8.42	8.13	8.6	8.49	8.86	8.5
D445 LT	-48°C	Low Temp Viscosity	cSt	36325.09	38427.23	27003.4	**	48529.97	47319.38
D4683 TBS	150°C	Tapered Bearing Shear Viscosity	cPs	2.69	2.59	2.73	2.68	2.88	2.78
D5800		Noack Volitility	wt%	10	12.4	12	14.3	12.2	12.2
D7109	100°C	Shear Stability							
		Viscosity @ 100C after 30 Passes	cSt	8.33	8.11	8.59	8.43	8.88	8.41
		Viscosity loss after 30 Passes	% Loss	1.07	0.25	0.12	0.71	-0.226	1.059
		Viscosity @ 100C after 90 Passes	cSt	8.22	8.07	8.55	8.47	8.95	8.46
		Viscosity loss after 90 Passes	% Loss	2.38	0.74	0.58	0.24	-1.016	0.471
D97		Pour Point	°C	-60	<-60	<-63	<-60	-60	-60
*Same as LO274845 **The sample is too viscous to obtain repeatable results.									

(Note: Two LO numbers are provided for Part 2 revised candidate b: LO271510 and LO274845. The oil is identical, but was provided in separate batches, thus identified differently for record keeping)

The following sections cover results from three additional standardized tests conducted on the revised candidates, including: high temperature corrosive bearing protection, foaming properties, and elastomer compatibility.

3.1.1 High Temperature Corrosive Bearing Test

The ASTM D6594 High Temperature Corrosive Bearing Test (HTCBT) was conducted on each revised candidate to determine the lubricants tendency to corrode various metals, specifically alloys of lead and copper commonly found in the construction of engine bearing shells. This test is conducted by immersing specimens of copper, lead, tin, and phosphor bronze in the candidate oil, which is then heated and blown with air for a specified period of time. After the test is completed the copper specimen is examined for color, and the oil is analyzed to determine corrosion products. Table 2 shows the HTCBT results for each revised candidate.

Table 2. ASTM D6594 HTCBT Results

High Temperature Corrosive Bearing Test				
	MIL-PRF-2104J Limits	Units	LO292039	LO306520
Copper (Cu) Increase	20 (max)	ppm	6	7
Lead (Pb) Increase	120 (max)	ppm	6	52
Tin (Sn) Increase	Report	ppm	0	0
Copper Strip D-130 Rating	3 (max)	-	1b	1b
	Pass/Fail?	-	Pass	Pass

As shown, both of the revised candidates passed the HTCBT test based on limits established in the MIL-PRF-2104J specification. Candidate LO306520 did show an increased accumulation of lead suggesting more aggressive corrosion than LO292039, but was still well below the 120ppm maximum limit as specified in MIL-PRF-2104J.

3.1.2 Foaming Properties

The ASTM D892 Foaming test determines the foaming characteristics of lubricating oils at two specified temperatures. This test aims to empirically rate the foaming tendency and stability of lubricating oils. This test is conducted by maintaining specified volume of lubricant at a specific temperature and injecting air into it at a constant rate for 5 minutes. The volume of foam formed is then recorded and the air supply is removed, allowing the oil to settle for an additional 5 minutes. After the settling time, the final volume of foam remaining is reported. Separate oil quantities are used for test sequence 1 and 2, but test sequence 3 reuses the same oil from test sequence 2 after cooling. Table 3 shows the foaming results for each revised candidate.

Table 3. ASTM D892 Foaming Characteristics

Foaming Characteristics				
Seq.	Temp.	MIL-PRF-2104J Limits	LO292039	LO306520
Seq 1	24C	10/0	0/0	0/0
Seq 2	93C	20/0	10/0	0/0
Seq 3	24C	10/0	0/0	0/0
Volume of foam (mL) after 5 minutes blowing/Volume of foam (mL) after 10 minutes settling time				

As shown, both of the revised candidates passed the foaming test based on limits established in the MIL-PRF-2104J specification. Apart from some small foaming present in LO292039 after the initial 5 minutes of air injection at 93 °C, no other foam accumulation was reported.

3.1.3 Elastomer Compatibility

The ASTM D7216 Elastomer Compatibility test evaluates the compatibility of automotive engine oils with common elastomers typically used in automotive sealing applications. Compatibility is determined by measurement of the volumetric change, durometer hardness, and tensile properties of elastomer specimens after being immersed in the candidate oils for a specified time and temperature. The elastomers evaluated by this test includes nitrile, polyacrylate, fluoroelastomer, silicon, and vamac. Table 4 shows the compatibility results for the two latest revision SCPL candidates.

Table 4. ASTM D7216 Elastomer Compatibility Results

Elastomer Compatilibty				
Elastomer	Batch	Acceptance Limits	LO292039	LO306520
Nitrile	**NBRBC14**			
	Volume Change	5.62 to -3.62	-0.19	1.66
	Hardness	8 to -6	5	4
	Tensile Strength	17.3 to -49.6	0.2	0.8
	Elongation	15.7 to -66.8	-40	-37.2
Polyacrylate	**ACMBC14**			
	Volume Change	5.62 to -3.62	-1.22	0.7
	Hardness	9 to -6	3	1
	Tensile Strength	26.2 to -23.2	-0.2	2.2
	Elongation	19.1 to -44.1	-5.9	-0.8
Fluoroelastomer	**FKMBC14**			
	Volume Change	5.13 to -2.13	0.74	0.96
	Hardness	8 to -6	0	0
	Tensile Strength	13.9 to -81.1	-50.6	-37.4
	Elongation	16.3 to -86.3	-48.4	-38.1
Silicon	**VMQBC13**			
	Volume Change	26.84 to -4.50	22.05	20.62
	Hardness	6 to -21	-18	-18
	Tensile Strength	15.7 to -50.7	-8.7	-7.1
	Elongation	28.1 to -38.1	-2.5	-8.4
Vamac	**MACBC9**			
	Volume Change	20.90 to -4.67	9.32	11.9
	Hardness	6 to -11	-4	-5
	Tensile Strength	17.1 to -28.0	-7.9	-2.4
	Elongation	19.0 to -43.0	-28.5	-28.8
		Pass/Fail?	Pass	Pass

As shown, both candidates met the specified acceptance limits as defined in the test method. This suggests that both oils should be compatible with typical engine seal applications, and should not be susceptible to the formation of leaks.

3.2 TRANSMISSION TESTING

Transmission frictional property testing conducted on each of the revised candidates included: Allison C4 graphite and paper testing, and Caterpillar TO-4M sequences 1220, 1222, and friction retention (FRRET). Results are discussed below in the following sections. Full test reports are included in Appendix A.

3.2.1 Allison C4 Testing

The following outlines the individual results for the C4 graphite and paper-composite testing.

Graphite

Table 5 and Table 6 show the C4 graphite results for revised candidates LO292039 and LO306520 respectively. Each is shown with its preceding results from SCPL development Part 1 and Part 2. Since the previous testing was completed, the C4 Graphite test was updated to Batch 45 friction material, and the C4 specification has been replaced by the Allison TES-439 specification. All previous testing was completed using Batch 44 material under the C4 spec. Unfortunately since the C4 spec is obsolete, Batch 45 limits were only established for the TES-439 specification. As a result, direct read across to previous C4 specification limits is not possible. The new TES-439 limits for Batch 45 hardware is as follows:

- Slip time (seconds): 0.73 to 0.89
- Midpoint coefficient: 0.085 to 0.105

These limits are applied to the Cycle 5500 results only, and when analyzing the results from the revised SCPL candidates, both candidates meet the new TES-439 specification.

Table 5. Allison C4 Graphite Results – LO292039

Initial Candidate

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO251746**	Test Number:	**C4-7-1285**
Lab Fluid Code:	**LO-251746**	Fric. Plate Batch:	**Batch 44**
Completion Date:	**7/21/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.81	0.90	11.11	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.072	0.048	-33.333	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.090	0.084	-6.667	F
Static Friction Coeff.	N/A	N/A	0.142	0.136	-4.225	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.160	0.153	-4.375	
0.25 Second Low Speed Coeff.	N/A	N/A	0.149	0.142	-4.698	

1st Revision

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO271510**	Test Number:	**C4-4-1342**
Lab Fluid Code:	**271510**	Fric. Plate Batch:	**Lot 44**
Completion Date:	**10/15/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.76	0.81	6.58	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.086	0.077	-10.465	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.097	0.094	-3.093	P
Static Friction Coeff.	N/A	N/A	0.140	0.128	-8.571	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.164	0.148	-9.756	
0.25 Second Low Speed Coeff.	N/A	N/A	0.147	0.140	-4.762	

2nd Revision

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO292039**	Test Number:	**C4--9-1449**
Lab Fluid Code:	**292039**	Fric. Plate Batch:	**Lot 45**
Completion Date:	**1/30/2014**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	Note: TES-228 (C4) specification obsolete. Batch 45 limits only apply to test conducted for Allison TES-439 and TES-295 specifications.		0.71	0.78	9.86	N/A
0.2 Second Dynamic Coeff.			0.097	0.082	-15.464	
Mid-Point Fric. Coeff. Min.			0.106	0.097	-8.491	N/A
Static Friction Coeff.			0.148	0.136	-8.108	
Low Speed Peak Fric. Coeff.			0.169	0.160	-5.325	
0.25 Second Low Speed Coeff.			0.156	0.145	-7.051	

Table 6. Allison C4 Graphite Results – LO306520

Initial Candidates

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY
(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO253071**	Test Number:	**C4-8-1286**
Lab Fluid Code:	**LO-253071**	Fric. Plate Batch:	**BATCH 44**
Completion Date:	**7/22/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.79	0.91	15.19	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.084	0.063	-25.000	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.082	-11.828	F
Static Friction Coeff.	N/A	N/A	0.129	0.112	-13.178	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.154	0.136	-11.688	
0.25 Second Low Speed Coeff.	N/A	N/A	0.130	0.123	-5.385	

1st Revision

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY
(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO268869**	Test Number:	**C4-3-1341**
Lab Fluid Code:	**268869**	Fric. Plate Batch:	**Lot 44**
Completion Date:	**10/14/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.75	0.86	14.67	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.090	0.067	-25.556	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.099	0.087	-12.121	F
Static Friction Coeff.	N/A	N/A	0.132	0.113	-14.394	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.138	0.123	-10.870	
0.25 Second Low Speed Coeff.	N/A	N/A	0.126	0.112	-11.111	

2nd Revision

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY
(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO306520**	Test Number:	**C4-8-1459**
Lab Fluid Code:	**306520**	Fric. Plate Batch:	**Lot 45**
Completion Date:	**3/10/2014**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	Note: TES-228 (C4) specification obsolete. Batch 45 limits only apply to test conducted for Allison TES-439 and TES-295 specifications.		0.71	0.86	21.13	N/A
0.2 Second Dynamic Coeff.			0.101	0.073	-27.723	
Mid-Point Fric. Coeff. Min.			0.105	0.089	-15.238	N/A
Static Friction Coeff.			0.121	0.103	-14.876	
Low Speed Peak Fric. Coeff.			0.150	0.123	-18.000	
0.25 Second Low Speed Coeff.			0.122	0.113	-7.377	

Paper

Table 7 and Table 8 show the C4 paper results for revised candidates LO292039 and LO306520 respectively. Unlike the graphite tests, these evaluations still had sufficient hardware available to run consistent with previous SCPL development testing, despite the C4 specification being replaced with TES-439. As shown, candidate LO292039 passed both limits for the paper testing, while candidate LO306520 still experienced a failure on the midpoint coefficient of friction. Much like previous testing the result was borderline early in the test, but as cycling progressed the friction response moved into an acceptable range. This response would not be expected to cause significant compatibility issues within military transmissions.

Table 7. Allison C4 Paper Results – LO292039

Initial Candidates

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO-251746**	Test Number:	**C2-6-1551**
Lab Fluid Code:	**251746**	Fric. Plate Batch:	**BATCH 5**
Completion Date:	**07/23/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.470	0.420	-10.64	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.103	0.120	16.50	P
Static Friction Coeff.	N/A	N/A	0.173	0.160	-7.51	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.197	0.173	-12.18	
0.25 Second Low Speed Coeff.	N/A	N/A	0.182	0.165	-9.34	

1st Revision

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO271510**	Test Number:	**C2-4-1574**
Lab Fluid Code:	**271510**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**10/17/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.500	0.430	-14.00	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.095	0.118	23.16	P
Static Friction Coeff.	N/A	N/A	0.173	0.158	-8.67	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.187	0.166	-11.23	
0.25 Second Low Speed Coeff.	N/A	N/A	0.171	0.163	-9.94	

2nd Revision

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO292039**	Test Number:	**C2-7-1615**
Lab Fluid Code:	**LO292039**	Fric. Plate Batch:	**LOT 6**
Completion Date:	**1/29/2014**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.500	0.430	-14.00	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.096	0.116	20.83	P
Static Friction Coeff.	N/A	N/A	0.170	0.152	-10.59	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.185	0.162	-12.43	
0.25 Second Low Speed Coeff.	N/A	N/A	0.176	0.156	-11.36	

Table 8. Allison C4 Paper Results – LO306520

Initial Candidates

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO-253071**	Test Number:	**C2-7-1552**
Lab Fluid Code:	**253071**	Fric. Plate Batch:	**Batch 5**
Completion Date:	**07/25/2010**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.540	0.450	-16.67	**P**
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.087	0.114	31.03	**F**
Static Friction Coeff.	N/A	N/A	0.161	0.125	-22.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.173	0.135	-21.97	
0.25 Second Low Speed Coeff.	N/A	N/A	0.163	0.131	-19.63	

1st Revision

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO268869**	Test Number:	**C2-3-1573**
Lab Fluid Code:	**268869**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**10/15/2011**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.530	0.460	-13.21	**P**
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.093	0.111	19.35	**F**
Static Friction Coeff.	N/A	N/A	0.103	0.111	7.77	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.102	0.115	12.75	
0.25 Second Low Speed Coeff.	N/A	N/A	0.095	0.111	16.84	

2nd Revision

ALLISON C- 4 PAPER FRICTION TEST

Sponsor Fluid Code:	**LO306520**	Test Number:	**C2-8-1616**
Lab Fluid Code:	**306520**	Fric. Plate Batch:	**Lot 6**
Completion Date:	**3/9/2014**	Steel Plate Batch:	**10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.520	0.460	-11.54	**P**
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.094	0.110	17.02	**F**
Static Friction Coeff.	N/A	N/A	0.118	0.132	11.86	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.118	0.135	14.41	
0.25 Second Low Speed Coeff.	N/A	N/A	0.117	0.134	14.53	

3.2.2 Caterpillar TO-4M

Table 9 and Table 10 show the Caterpillar TO-4M results for revised candidates LO292039 and LO306520 respectively. Each is shown with its preceding results from SCPL development Part 1 and Part 2. Both candidates continue to struggle with various areas of the testing, and both do not meet limit conditions in comparison to reference oils. As with previous testing, most failures observed appeared to be borderline overall, with only small segments of the resulting data falling outside reference oil limit lines, and the majority remaining in acceptable ranges. This response is again not expected to cause significant compatibility issues within military transmissions. (Note: CAT TO-4M Sequence 1222 is not a specification requirement called out in MIL-PRF-

2104. Its inclusion into the test matrix was more focused on gathering supplemental friction data on alternative materials.)

Table 9. Caterpillar TO-4M Results – LO292039

CAT TO-4	LO251746	LO271510	LO292039
Sequence 1220	***initial***	***1st Revision***	***2nd Revision***
Dynamic Coef vs Cycle	Fail	Pass	Fail
Dynamic Coef vs Load	Fail	Pass	Fail
Dynamic Coef vs Speed	Fail	Pass	Fail
Energy Limit	Pass	Pass	Pass
Static Coef vs Load	Fail	Pass	Pass
Static Coef vs Speed	Fail	Pass	Pass
Energy Limit	Pass	Pass	Pass
Total Wear	0.039	0.006	0.02
Sequence 1222			
Dynamic Coef vs Cycle	Fail	Fail	Pass
Dynamic Coef vs Load	Fail	Fail	Pass
Dynamic Coef vs Speed	Fail	Fail	Pass
Energy Limit	Pass	Pass	Pass
Static Coef vs Load	Fail	FP	Pass
Static Coef vs Speed	Fail	Pass	Pass
Energy Limit	Pass	Pass	Pass
Total Wear	0.007	0.029	0.033
Friction Retention			
	Pass	N/A	Fail (boarderline)

Table 10. Caterpillar TO-4M Results – LO306520

CAT TO-4	LO253071	LO268869	LO306520
Sequence 1220	***initial***	***1st Revision***	***2nd Revision***
Dynamic Coef vs Cycle	Pass	Pass	Fail
Dynamic Coef vs Load	Pass	Pass	Fail
Dynamic Coef vs Speed	Pass	Pass	Pass
Energy Limit	Pass	Pass	Pass
Static Coef vs Load	Pass	Pass	Pass
Static Coef vs Speed	Pass	Pass	Pass
Energy Limit	Pass	Pass	Pass
Total Wear	0.039	0.016	0.012
Sequence 1222			
Dynamic Coef vs Cycle	Fail	Fail	Fail
Dynamic Coef vs Load	Fail	Fail	Fail
Dynamic Coef vs Speed	Fail	Fail	Pass
Energy Limit	Pass	Pass	Fail
Static Coef vs Load	Fail	Fail	Fail
Static Coef vs Speed	Pass	Fail	Pass
Energy Limit	Pass	Pass	Fail
Total Wear	0.03	0.029	0.02
Friction Retention			
	Pass	N/A	Pass

3.3 HIGH TEMPERATURE 2-CYCLE DIESEL TESTING

As a follow on to work completed during SCPL development Part 2, additional 2-cycle diesel compatibility testing was conducted to assess the SCPL's ability to protect this unique engine architecture, this time under high temperature desert type operation. Funding was originally provided to evaluate both revised SCPL candidates only, but upon preparation of testing, a change in the ring pack design of parts procured through Detroit Diesel was noted. TFLRF identified the change and brought it to the attention of TARDEC to discuss testing impact. The concern was that the change in the oil control rings had the potential to affect high temperature testing results, and obscure any comparison to previous work completed during Part 2. After discussion, three options were identified:

- Option 1 - Run both (2) funded tests as written in the SOW (both revised SCPL candidates) with new oil rings – all at high temperature.
- Option 2 - Run one revised candidate with new style oil ring, and the second revised candidate with old style oil rings – all at high temperature.
- Option 3 - Run one (generic) SCPL and one baseline 15W-40 evaluation, both with new style oil rings, both at high temp.

Option three was selected as the best course for testing as it better balanced information that was most beneficial to the SCPL program, and helped identify any shifts between the new style parts versus results achieved during testing conducted in Part 2 using the old style parts. The SOW was modified and progress continued. The following sections review the construction of the engine test stand and description of test cycle covered in Part 2, and discusses the results attained from the high temperature evaluations using MIL-PRF-2104H 15W40 and the SCPL.

3.3.1 Test Stand Construction.

The same test installation used in SCPL development Part 2 was utilized for the high temperature compatibility evaluations. Testing included the current MIL-PRF-2104H 15W40 OE/HDO to establish a known baseline condition (consistent with actual current military applications), followed by testing of a single revised SCPL candidate to determine general SCPL high temperature compatibility. Due to test timing issues, neither of the final candidates (LO306520 or LO292039) were available to conduct engine testing, so the revised candidate B from SCPL development Part 2 (LO271510,LO274845) was used for the SCPL test.

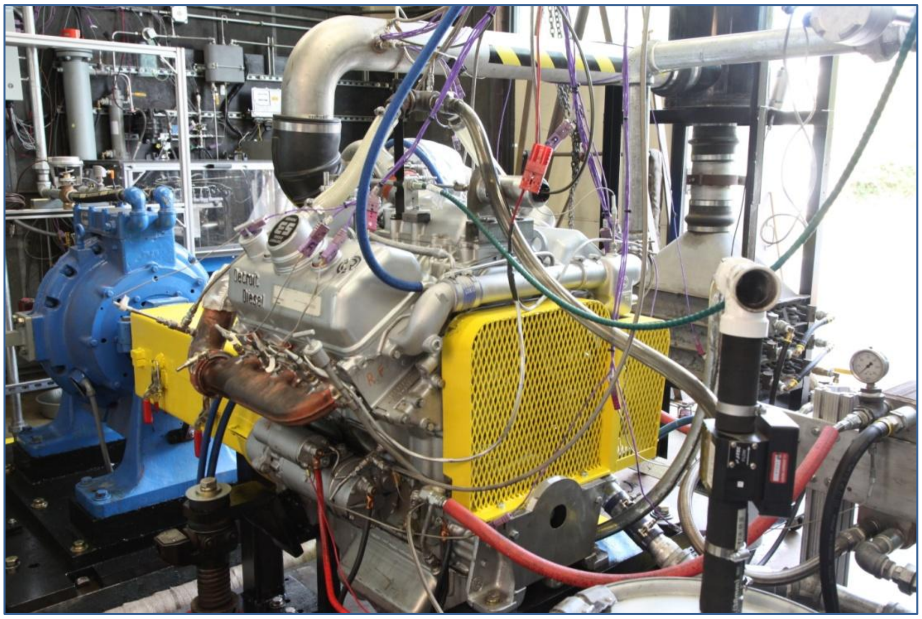

Figure 1. Detroit Diesel 6V53T Test Cell Installation

The DDC 6V53T used in these evaluations was in its military configuration, built according to the specifications for the M113A3 Armored Personnel Carrier (APC). As tested it produced approximately 235hp and 560ft-lb of torque (using JP-8). A picture of the DDC 6V53T engine installation can be seen in Figure 1. The engine was mounted in an engine dynamometer test cell and equipped with all necessary equipment needed to operate the engine, with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e., alternator, cooling fan, etc.). The bulleted list below outlines the basic test stand configuration utilized:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as engine speed and output power/torque.
- Engine loading was provided by a 300hp Midwest 1519 wet-gap eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer

controlled overall engine speed, while the throttle actuation system adjusted the fuel rack position to manipulate engine load.

- A liquid-liquid heat exchanger was used to regulate the engine water jacket temperature with building supplied process water.
- The oil filter housing and oil cooler were removed from the engine and their inlets and outlets were plugged. The original oil filter housing was then remotely mounted to the test stand and connected via steel braided Teflon lines back to the engines oil supply port. A remote liquid-liquid heat exchanger was then added in series with the oil filter, and plumbing was then returned back to the engine at the left lower front cover. These modifications were completed to allow independent control of the engine oil sump temperature by removing interaction between the oil cooler and the engine water jacket. The changes also allowed easier access to the engine air box covers for bore inspections. Changes made to the engine had no impact on its internal oiling/lubrication.
- Fuel was supplied from bulk storage tanks to an engine “day-tank” that served as a common location for the engine supply and return lines. The engine’s fuel consumption was monitored by a Mircomotion coriolis flow meter by measuring the make-up fuel required to maintain the day tank at a constant volume.
- Inlet fuel temperature was controlled by a heater control loop to maintain steady inlet temperature throughout testing. The control loop maintained a reservoir of a glycol-water solution at a specified temperature, and was then used as a heat source to elevate the temperature of incoming fuel to the desired set point through a liquid-liquid heat exchanger.
- Engine inlet air was drawn past chilled (process water) water cores to lower intake air temperatures prior to the engine air filtering system. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air restriction prior to the turbocharger inlet.
- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled via a butterfly valve located in

the exhaust stack between the engine and the buildings common exhaust header before exiting the test cell.

- Engine blow-by gases were ducted into a drum to capture any entrained oil, and then vented through a vortex shedding flow meter to monitor engine blow-by rates. Waste gasses were then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP-8 blended at location from commercially available Jet-A with a double max-treat rate of lubricity enhancer DCI-4A.

3.3.2 Test Cycle Operation

Consistent with testing conducted during SCPL development Part 2, the 6V53T engine was evaluated based on procedures outlined in Federal Test Method (FTM) Standard No. 791C, Method 355, Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions [9]. Modifications were again made to selected operating conditions, as the engine output and torque characteristics of the current 6V53T model have changed since the original establishment of the test method. Despite this, the general operation of the engine test cycle from the FTM remained unchanged. The test cycle included cyclic modes of 0.5 hours at idle, 2 hours at max power, 0.5 hours at idle, and 2 hours at max torque. This was repeated 4 times daily for a total of 20 hours runtime, accumulating 240 hours over a 12 day period. Daily operation was followed by a 4 hour engine off soak prior to the next day’s running to allow thermal cycling of the lubricant. The cycle called out in this FTM was based off of work reported under CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [10]. The test cycle outlined was originally correlated to 4,000 miles of actual military tracked vehicle proving ground operation.

At the start of the test and every 60 hours of operation an engine airbox inspection was completed to assess the condition of the piston skirts, ring faces, and cylinder liners. This provides quasi-real time monitoring of the oils performance in protecting critical engine components throughout the test duration. Bore inspections were completed by passing a borescope through the engines airbox covers and liner intake ports while each piston was at bottom dead center (BDC), and visually rating the condition of the liner surface. The original FTM stated that if any single liner experienced greater than 30% scuffing while other liners remained in good condition, a single cylinder kit could be replaced and testing continued. This could only be completed once during the test cycle, otherwise testing was to be terminated. If at any time multiple liners experienced severe scuffing, and were deemed progressive in nature, the test was to be terminated. Severe scuffing could potentially lead to failure of the liner to block O-rings and cause catastrophic engine damage.

At all times engine oil sump and coolant temperatures were controlled to ensure test consistency and severity for each lubricant tested. In general, no engine oil changes were made during the test cycle, and testing was continued until the completed 240 hours, or upon the occurrence of major oil degradation or liner scuffing. Some variation to this procedure was done during the SCPL evaluation and is discussed below. Table 11 below shows the overall operation conditions used for the 6V53T testing.

Table 11. DDC 6V53T Operating Conditions

Parameter	Max Power	Max Torque
Engine Speed [RPM]	2800 +/- 25	1600 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5
Oil Sump [°F]	260+/- 5	260 +/- 5

Used engine oil samples were collected every 20 hours for analysis to assess the condition of the lubricant and to determine test termination if necessary. Extreme liner scuffing can be identified by sharp changes in iron accumulation rates during testing. Analytical tests conducted on daily samples are outlined below in Table 12. The engine oil level was replenished daily after sampling, and all engine oil additions and samples were weighed throughout testing to track engine oil consumption.

Table 12. DDC 6V53T Used Oil Analysis Tests

Test Method	Description
ASTM D445	Kinematic Viscosity @ 100 °C
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number
ASTM D5185	Wear Metals by ICP

3.3.3 Engine Metrology and Ratings

Each lubricant was evaluated after completing an "in-frame" rebuild of the 6V53T engine. The primary item of focus for 2-cycle compatibility is the engine's liner and piston, commonly referred to as the cylinder kit. Each cylinder kit underwent a metrology process before testing to fully document its starting condition. The pre-test metrology process included measurements of the cylinder kit, as well as other critical engine parameters to ensure integrity of the engine, including:

- Piston ring clearances (end gap & side clearance, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Upper oil control ring and expander tension (reference only measurement)
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
    - 13 mm from top
    - 25 mm above ports
    - 25 mm below ports
    - 13mm from bottom
- Liner surface finish (single pass above ports)
- Engine block bore (top & bottom, T/AT & F/B)
- Slipper bushing tin plate thickness (reference only measurement)
- Slipper bushing mass
- Connecting rod bearing mass
- Connecting rod bearing to crank journal clearance
- Exhaust valve recession
- Crankshaft endplay

After the inspection and metrology process was completed, the engine was reassembled according to factory specifications. Any parts requiring lubrication during assembly were lubricated using an additive free lubricant in order to remove any bias on subsequent lubricant test data. At the completion of each test, the engine was disassembled and inspected. This allowed for documentation of wear experienced over the test duration, and assessment of the piston skirt, rings, and liner condition. Similar to pretest metrology, post-test metrology procedures included measurements of:

- Piston ring clearances (end gap only, all)
- Top, second, and third ring radial thickness
- Piston ring mass, all
- Piston skirt diameter
- Liner bore (free standing, T/AT & F/B) at:
    - 13mm from top
    - 25mm above ports
    - 25mm below ports
    - 13mm from bottom
- Slipper bushing mass
- Connecting rod bearing mass

Internal component ratings were also conducted to quantify the amount and location of carbonaceous and lacquer type deposits present, and wear experienced during testing. This process was completed following industry standardized ASTM ratings procedures [11]. Ratings included piston deposits, ring face distress, piston skirt and liner ratings, intake port plugging, and slipper bushing exposed copper.

3.3.4 MIL-PRF-2104H High Temperature Results

The MIL-PRF-2104H high temperature evaluation successfully completed the full 240hr test schedule. At approximately 100hrs into testing, a low power condition on the engine was observed. The used oil analysis, bore inspection, and engine blow by data did not suggest a mechanical engine issue with the engine itself, so investigation into the engine subsystems was completed. Ultimately the fuel transfer pump relief piston was found faulty, resulting in low fuel supply pressure to the injectors and the reduced power. In addition three of the six injectors demonstrated poor spray performance and chatter when checked on a calibration bench. A new fuel transfer pump, replacement injector, and two new injector tips were installed, and testing continued. After repairs the engine output was verified consistent with its original output.

Bore inspections during the 2104H test at the 0 and 60hrs showed that all liners were void of any scuffing present. At 120hrs liner 2R showed approximately 7% scuffing, and at 180hrs 10% scuffing. All others locations showed no evidence of scuffing. Used oil analysis past the last airbox inspection at 180hrs showed pronounced jumps in iron concentration (220hr and 240hr samples specifically). This suggested that additional scuffing was occurring in the engine, and was most likely attributed to further scuffing of cylinder 2R. During the teardown and ratings at the end of testing, liner 2R was found to be 90% scuffed. All other liners ranged between zero to 2% scuffing. Although not a perfect result, the test did demonstrate that the 2104H did protect the 2-cycle engine from failure despite the maintained high lubricant temperatures. Per the original FTM method the single scuffed liner result was removed from the reporting as an outlier since all other locations showed little distress. After reviewing all post test metrology and ratings results with the 2R results dropped, it was found that the 2104H high temperature test closely tracked the results observed during the ambient temperature evaluations conducted during SCPL development Part 2, with the exception of the top compression ring condition. All top compression rings in high temperature test were found to be collapsed between 25-50%. This means the piston ring has lost some of its tension compared to its pre-test condition, and its overall at rest OD has decreased. The cause for this was not readily identified. In general, ring collapse occurs when pressure differentials occur between the inner and outer diameter of the ring during operation, and is a complex result of radial ring pressures and interactions from combustion pressure and temperature. The full test report is presented in Appendix B.

3.3.5 Revised SCPL Candidate Results

Unlike the 2104H evaluations, the revised SCPL high temperature evaluation in the 6V53T did not complete the 240hr evaluation as a result of uncontrolled scuffing during operation past 60hrs of testing. As previously mentioned, revised candidate LO274845 from SCPL development Part 2 was initially tested in the high temperature evaluation due to availability at the time of testing. After initiation testing progressed smoothly to the first bore inspection at 60hrs. At that time no cylinder showed any evidence of scuffing. However after the 60hr mark, iron accumulation concentrations in 80, 100, and 120hr used oil samples began showing exponential growth. This was immediately suspected as an indicator of scuffing, and at the 120hr bore inspection liner 2R was found to be 80% scuffed (see Figure 2), and 2L and 1R showed 14% and 15% respectively. Based on the magnitude of scuffing present and the procedures of the FTM, cylinder kit 2R was removed from the engine and replaced with an unmeasured cylinder kit and testing was continued. The intentions were that this single liner result would be dropped as an outlier if testing continued successfully. However at 160hrs, an unscheduled bore inspection was conducted due to lagging used oil analysis results, and cylinder 1R was found to be 99% scuffed (Figure 3). Once the used oil analysis caught up to real time, results showed continued exponential iron accumulation in the oil since the occurrence of the first scuffing event. At this time testing was halted as it appeared that the SCPL was not able to provide adequate protection.

Figure 2. SCPL High Temp 6V53T Evaluation, Liner 2R Removed at 120hrs

Figure 3. SCPL High Temp 6V53T Evaluation, Liner 1R Removed at 160hrs

Discussions were held with TARDEC regarding the test progress. Of particular interest was the higher NOACK volatility of candidate LO274845. It was desired to determine if the scuffing tendency of the SCPL was attributed to the high NOACK, or if the general low viscosity profile combined with the elevated operating temperatures was the primary culprit. Since the test was not complete and funding was still proficient, it was determined that later lower NOACK version of the same candidate SCPL was to be attempted in the remaining test hours to see if any changes in performance could be observed.

At 160hrs all the right hand side cylinder kits were replaced with new measured kits, and testing was continued with a new oil charge of the now available revised candidate LO292039 (NOACK of 12.2 wt% vs LO274845 NOACK of 14.3%). The engine was operated for an additional 40hrs accumulating a total of 200hrs of high temperature operation when the iron accumulation rates were again observed to be rapidly climbing. A bore inspection at 200hrs confirmed that cylinder 2L and 3L were now 40% and 85% scuffed respectively, and heavy scratching (a precursor to scuffing) was noted on the newly installed right hand cylinder kits. Testing at this time was terminated and the engine was disassembled for final inspection.

Upon removal, the right hand side pistons with only 40 hours of operation all showed heavy scuffing on the thrust side skirts (see Figure 4, Figure 5, and Figure 6). This suggested that liner scuffing of the right hand side was imminent, and the lower NOACK of the revised SCPL candidate did not provide improved protection. With the multiple parts changes that occurred during testing, only minimal post test ratings and metrology was completed (completed only on parts from the left bank that operated the full 200hrs on test). The resulting test report (partial) of the high temperature SCPL test is presented in Appendix C.

Figure 4. SCPL High Temp 6V53T Evaluation, 160hr 1R Replaced Piston Removed at 200hrs

Figure 5. SCPL High Temp 6V53T Evaluation, 160hr 2R Replaced Piston Removed at 200hrs

Figure 6. SCPL High Temp 6V53T Evaluation, 160hr 3R Replaced Piston Removed at 200hrs

3.4 Standardized Mack T-12 Durability

The final testing conducted on the revised SCPL candidates was the industry standardized Mack T12 tests (ASTM D7422), which evaluated the wear performance of lubricants in turbocharged intercooled diesel engine equipped with exhaust gas recirculation (EGR) and operating on ultra low sulfur diesel (ULSD). Although the use of EGR and ULSD are not readily applicable to military applications, this test is an industry accepted wear test for CJ-4 qualification, and would provide insight on how the SCPL candidates which have been uniquely formulated for military applications would perform in current industry standardized testing. The Mack T-12 test was conducted for a total of 300hrs, with the first 100hrs operated at rated speed and power to generate specific soot levels in the oil, and the final 200hrs being operated at peak torque while over-fueling to maximize wear rates on piston rings an liners. The Mack T-12 test by procedure utilizes an oil adder system, in which the fixed total quantity of oil allowed for the test cycle is loaded into the engine and adder system at the start of testing. Thus oil consumption rates during the test be readily monitored and compared. The evaluated parameters of the test included the piston ring wear, cylinder liner wear, lead bearing corrosion, along with lubricant consumption and oxidation.

Both revised candidates LO292039 and LO306520 completed the full 300hr Mack T-12 test schedule, however results were varied. Results in industry are based on the ending “total Mack merits”, which numerically rate the liner, top ring, oil consumption, and lead concentration increases for the test. A passing lubricant needs to generate 1000 merits to be qualified for the CJ-4 specification, and 1300 merits for the Mack EO-O premium designation. The results for each revised candidate is as follows:

- LO292039 – 938.1 merits
- LO306520 – -1266.2 merits

Based on these results neither of the SCPL candidates “passed” the minimum requirements for CJ-4 approval. However upon closer inspection of the data, several key points can be derived. Full T-12 test reports for both candidates can be seen in Appendix D.

3.4.1 SCPL Candidate LO292039

Although not a passing result, the 938.1 merit rating is relatively good for the SCPL. Although short of the current CJ-4 requirements, this result does exceed previous category CI-4+ requirements. Recent changes to industry wide correction factors negatively affected the merit rating of the SCPL for the CJ-4 perspective, but overall top ring weight loss was observed to be good.

At the time of testing there was an industry wide variation in top ring weight loss and cylinder liner wear being observed in testing. Both of these issues can significantly impact overall oil consumption during testing, which in turn increases the severity of the testing as higher levels of wear metals accumulate in the oil compared to testing with lower consumption. For LO292039 the oil volume in the external oil adder system used was fully consumed by approximately

260hrs into testing, so the test was considered fairly severe based on the overall reduced oil volume maintained during the test.

Based on the actual results achieved, the high oil consumption observed, and known industry variation, it is plausible that if this oil where re-tested it could achieve the CJ-4 requirements.

3.4.2 SCPL Candidate LO306520

The LO306520 result of -1266.2 merits was unexpected. Past military application testing has shown the performance of both SCPL candidates to be very similar, so the large variance in T-12 results was initially surprising.

From reviewing the data the primary cause of the poor performance of this candidate was most strongly linked to the oil consumption rate that occurred during the test. Similar to that observed during testing of LO292039, the oil volume in the external oil adder during LO306520's evaluation test was also fully consumed, but at an earlier 219hrs of testing. As a result the final 81hrs of testing was conducted on the reduced oil volume increasing its test severity compared to that observed during the LO292039 evaluation. As previously discussed high oil consumption negatively impacts ring and liner wear, and for LO306520 the liner wear result was very poor. This directly drove down the resulting merit ratings for the test.

This again brings into question the current industry variation issues with top ring weight loss and liner wear as a result of the ring pack stability. It is unknown if the LO306520 evaluation may have been effected by these issues, and without additional testing, no further conclusions from the Mack T-12 test can be derived.

At this time it is recommended that all T-12 results should only be taken as cautionary result, with more regard being put on other military specific engine testing conducted with the SCPL candidates to determine their engine wear protection properties.

4.0 CONCLUSIONS

In conclusion we can see that the latest revised SCPL candidates still have areas where they can be improved upon for industry standardized testing. All testing in military applications apart from high temperature two cycle testing has shown positive results. The following conclusions can be made from these final test areas reported:

- Bench top analytical testing showed that both revised candidates exceed industry standards for high temperature bearing corrosion, foaming resistance, and elastomer compatibility.
- SCPL candidates still show borderline failures in some of the standardized transmission testing, but as previously analyzed, the failures that are occurring would not be expected to cause significant compatibility issues in military equipment due to the minimal excursions past limit lines developed in testing. All applied transmission testing conducted in the RAM-D Stryker testing and vehicles included in the SCPL field demonstrations has demonstrated that transmission function remains acceptable while using the SCPL candidates.
- Use of the SCPL in high temperature two cycle diesel engines is not advisable. The critical piston/liner architecture used in the two cycle diesel engines does not tolerate the combined low viscosity and increased operating temperatures, and results in uncontrolled liner scuffing. During more moderate operating conditions, as shown in the initial SCPL two cycle compatibility testing during SCPL Development Part 2, the SCPL can provide adequate two cycle protection.
- Results from the Mack T-12 test were varied. Neither SCPL candidate met the CJ-4 accreditation level, but test results are questionable based on industry wide consistency issues within the test.

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8. Brandt, A.C., Frame, E.A., "Transmission Bench Testing for Single Common Powertrain Lubricant Candidates", Draft Interim Report TFLRF No. 417, January 2012.

9. *"Performance of Engine Lubricating Oils in a Two-Cycle Diesel Engine Under Cyclic, Turbo-Supercharged Conditions"* Federal Test Method STD 791C, Method 355, September 1986.

10. Development of Military Fuel/Lubricant/Engine Compatibility Test, CRC Report 406, January 1967.

11. ASTM Deposit Rating Manual 20 (Formerly CRC Manual 20), ASTM International, West Conshohocken, PA, www.astm.org.

6.0 TFLRF SCPL REPORT BIBLIOGRAPHY

The following section lists all reports completed by TFLRF in support of the SCPL program since its inception. Some of the following were referenced in the preceding report, but the below listing outlines all reports related to the SCPL completed by TFLRF from approximately 2008-2015.

1. Brandt, A.C., et. al., "SAE J1321 Testing Using M1083A1 FMTV's," Interim Report TFLRF No. 404, March 2010

2. Wendel, G., "Feasibility of a Single Common Powertrain Lubricant: Hydraulic System Investigations at Low Temperatures" Interim Report TFLRF No. 411, January 2011

3. Brandt, A.C., et. al., "Feasibility of Using Full Synthetic Low Viscosity Engine Oil at High/Ambient Temperatures in U.S. Army Engines," Interim Report TFLRF No. 413, June 2011

4. Brandt, A.C., et. al., "Transmission Bench Testing for Single Common Powertrain Lubricant Development," Interim Report TFLRF No. 417

5. Brandt, A.C., et. al., "Single Common Powertrain Lubricant Development," Interim Report TFLRF No. 418, January 2012

6. Brandt, A.C., et. al., "Single Common Powertrain Lubricant (SCPL) Development Part 2," Interim Report TFLRF No. 442, May 2014

7. Frame, E. A., et. al., "Axle Lubricant Efficiency," Interim Report TFLRF No. 444, May 2014

8. Brandt, A.C., et. al., "Teardown and Inspection of the Cummins VTA-903 Evaluated using the Single Common Powertrain Lubricant," Interim Report TFLRF No. 450, August 2013

9. Brandt, A.C., et. al., "Inspection of Stryker Engines Evaluated using SCPL in a 20k Mile RAM-D Test," Interim Report TFLRF No. 452, April 2014

10. Brandt, A.C., et. al., “U.S. Army Field Demonstration of the Single Common Powertrain Lubricant (SCPL),” Draft Interim Report TFLRF No. 454, February 2015

11. Brandt, A.C., et. al., “Inspection of Stryker Transmissions Evaluated using SCPL in a 20k Mile RAM-D Test,” Interim Report TFLRF No. 457, August 2014

12. Brandt, A.C., et. al., “Single Common Powertrain Lubricant (SCPL) Development Part 3,” Interim Report TFLRF No. 462, February 2015

13. Brandt, A.C., et. al., “Evaluation of the Single Common Power Train Lubricant (SCPL) in the 1050HP AVDS-1790-8CR Engine,” Interim Report TFLRF No. 463, February 2015

APPENDIX A.

Transmission Bench Test Reports

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

This page has been AMENDED.
Initial: JW
Date: 3/24/14

Report on

ALLISON TRANSMISSION FLUID
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO292039

Test Number:
C4-9-1449

January 30, 2014

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

The results of this report relate only to the fluid tested.

VIII. Graphite Clutch Friction Test

Test Laboratory: SWRI
Test Number: C4-9-1449
Friction Plate Batch: LOT 45
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-292039
Sponsor Fluid Code: LO292039
Completion Date: 01/30/14

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0900	0.0837

	Before	After
Pack Clearance	0.4572	0.5588

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1428	10/16/13	MIL-PRF-2104H
C4-0-1429	10/18/13	MIL-PRF-2104H
C4-0-1440	01/04/14	MIL-PRF-2104H

	New	EOT
Viscosity at 40°C, cSt	45.21	38.21
Viscosity at 100°C, cSt	8.48	7.27
Iron Content, ppm	1	144

D5185	New Fluid (ppm)
Ba	<1
B	15
Ca	933
Mg	1323
P	1138
Si	5
Na	<5
Zn	1236

Name: Matthew Jackson
Signature:
Title: Manager
Date: 2/6/14

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO292039**	Test Number:	**C4-9-1449**
Lab Fluid Code:	**LO-292039**	Fric. Plate Batch:	**LOT 45**
Completion Date:	**1/30/2014**	Steel Plate Batch:	**10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.12	53	82	43	39	112	90
1000	1.22	49	79	36	43	95	81

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.71	113	158	103	55	180	166
2000	0.73	111	156	97	59	171	163
2500	0.75	109	155	91	64	185	163
3500	0.77	106	152	87	65	184	161
4000	0.77	105	151	85	66	181	158
4500	0.79	103	149	86	63	170	157
5000	0.79	103	145	86	59	177	156
5500	0.78	104	145	87	58	171	155

	Limits		**Results**		
	Min	Max	1,500 N	5,500 N	% Change
Slip Time Max.	N/A	N/A	0.71	0.78	9.86
0.2 Second Dynamic Coeff.	N/A	N/A	0.097	0.082	-15.464
Mid-Point Fric. Coeff. Min.	N/A	N/A	0.106	0.097	-8.491
Static Friction Coeff.	N/A	N/A	0.148	0.136	-8.108
Low Speed Peak Fric. Coeff.	N/A	N/A	0.169	0.160	-5.325
0.25 Second Low Speed Coeff.	N/A	N/A	0.156	0.145	-7.051

The Allison TES-228 (C4) specification is obsolete. Batch 45 limits apply only to tests conducted for Allison TES-439 and TES-295 specifications.

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO292039 **Test Number : C4-9-1449** **Completion Date : 1/30/2014**

Lab Fluid Code : LO-292039 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 45**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2130	2.1260	2.2100	2.1200	0.0870		0.0900
	120	2.2140	2.1370	2.2160	2.1270	0.0770		0.0890
	240	2.2070	2.1290	2.2030	2.1220	0.0780		0.0810
	Average					0.0807	0.0837	0.0867
STEEL SEPARATORS								
1	Top	1.7510	1.7510	1.7510	1.7510	0.0000		0.0000
	120	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	240	1.7520	1.7520	1.7520	1.7520	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7600	1.7600	1.7600	1.7600	0.0000		0.0000
	120	1.7570	1.7570	1.7570	1.7570	0.0000		0.0000
	240	1.7570	1.7570	1.7580	1.7580	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION WITH NO UNUSUAL DISCOLORATION. MICROMETER

(Anything Unusual) #0221190

Test Date: 1/30/2014

Operator's Name: MARK HOLMES

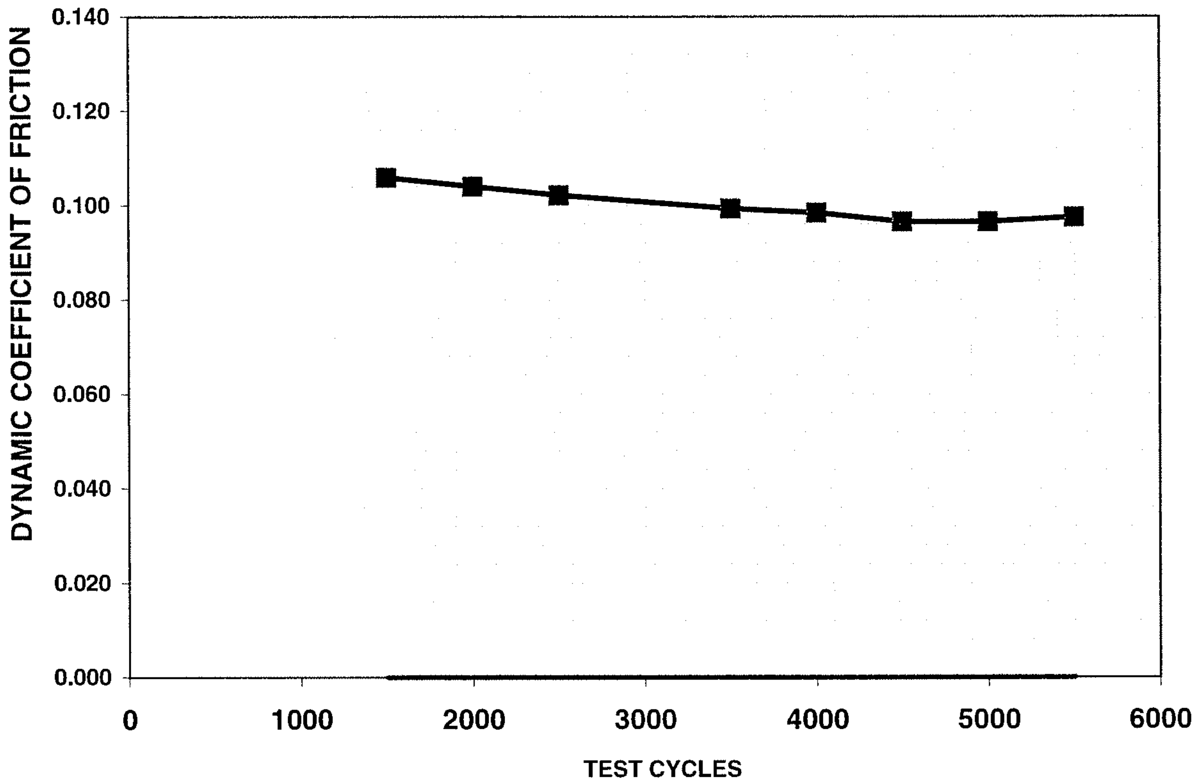
Reviewed By (Signature and Date)

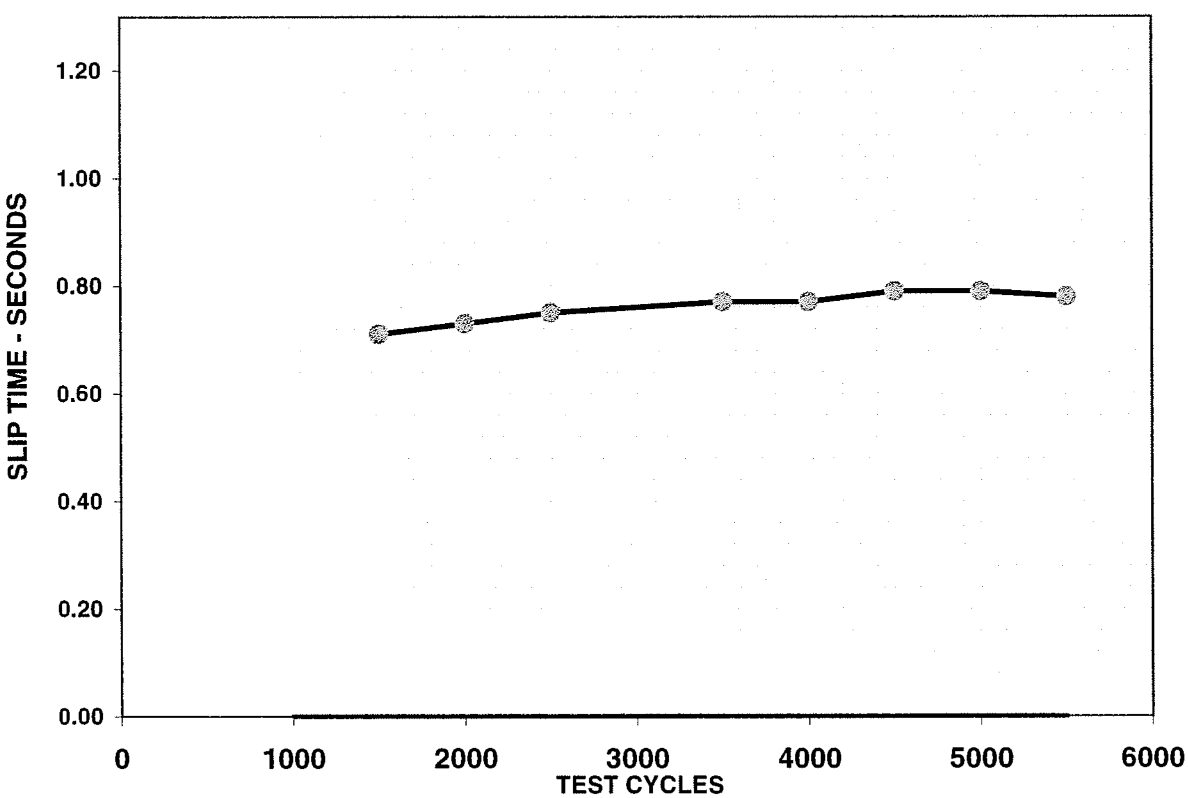
2/6/14

Pack ID#: 5134

ALLISON TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

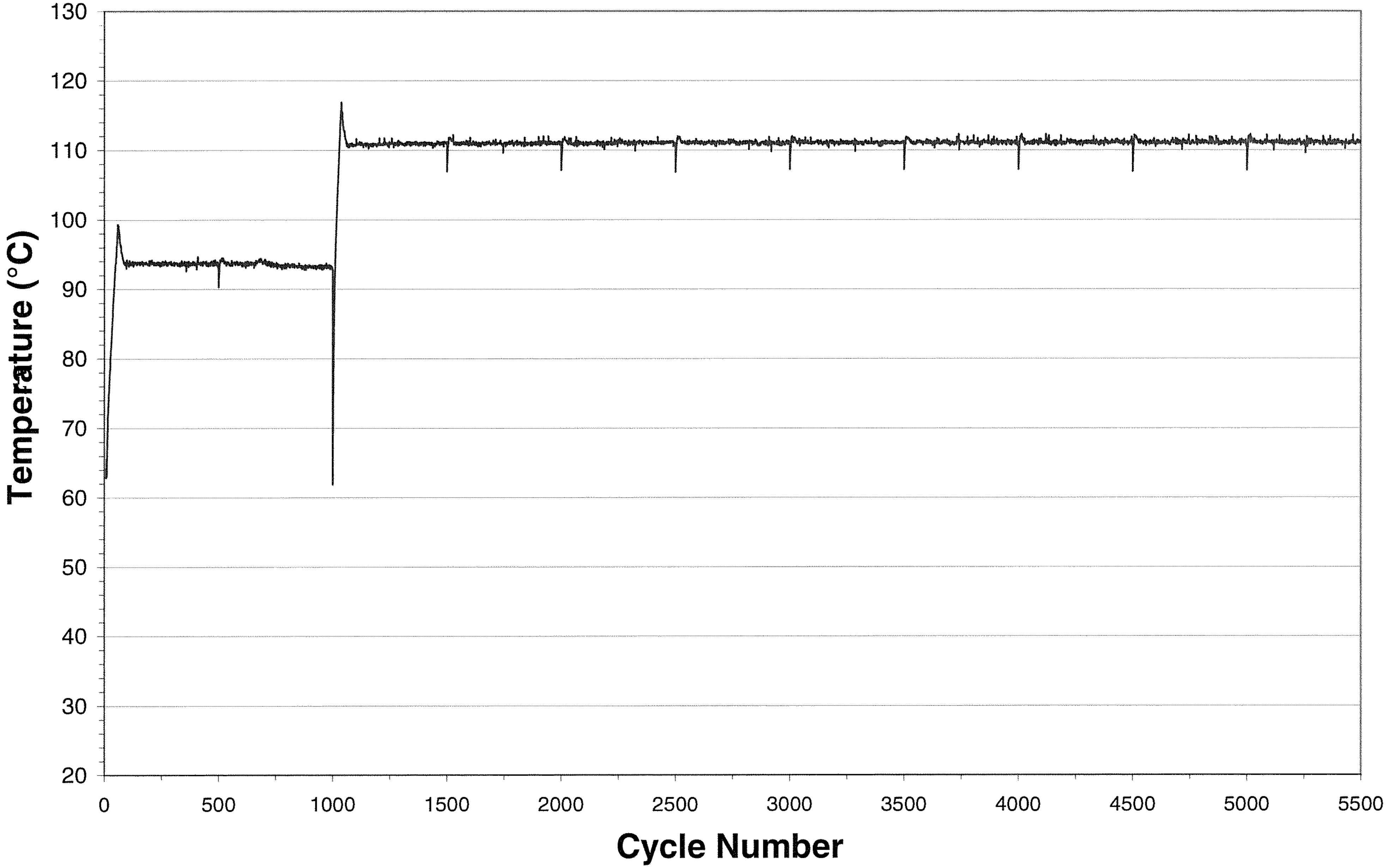
EOT Date: 1/30/2014 | Fluid Code: LO292039
Test Number: C4-9-1449 | Plate Batch: LOT 45
Steel Batch: 10/9/2008





C4-9-1449 LO292039

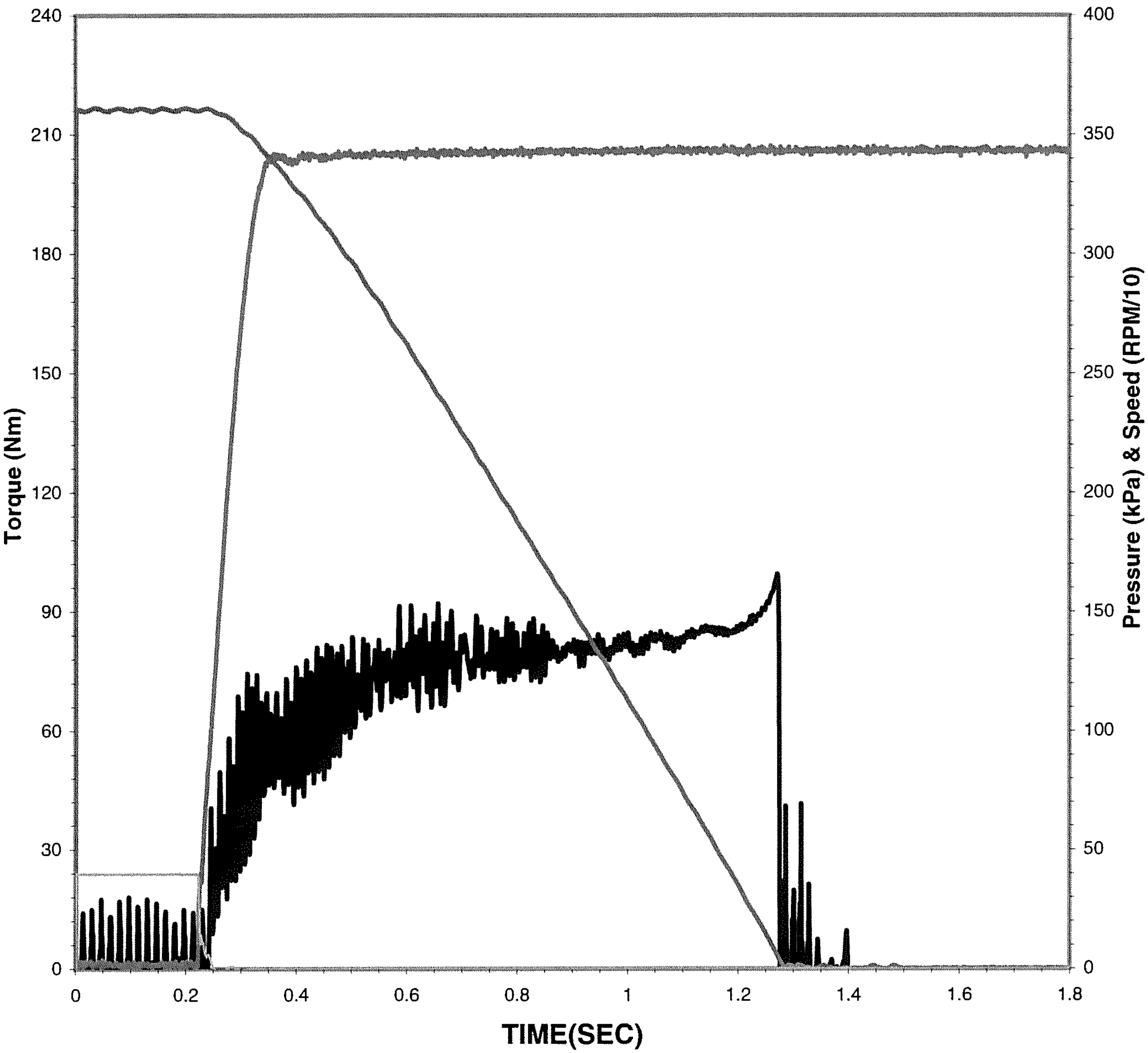
AVG: Phase A = 93.0 °C. Phase B = 111.0 °C



DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	2:36:54
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	10
Temperature:	65.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	341 kPa (345 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.052 Sec

Torque

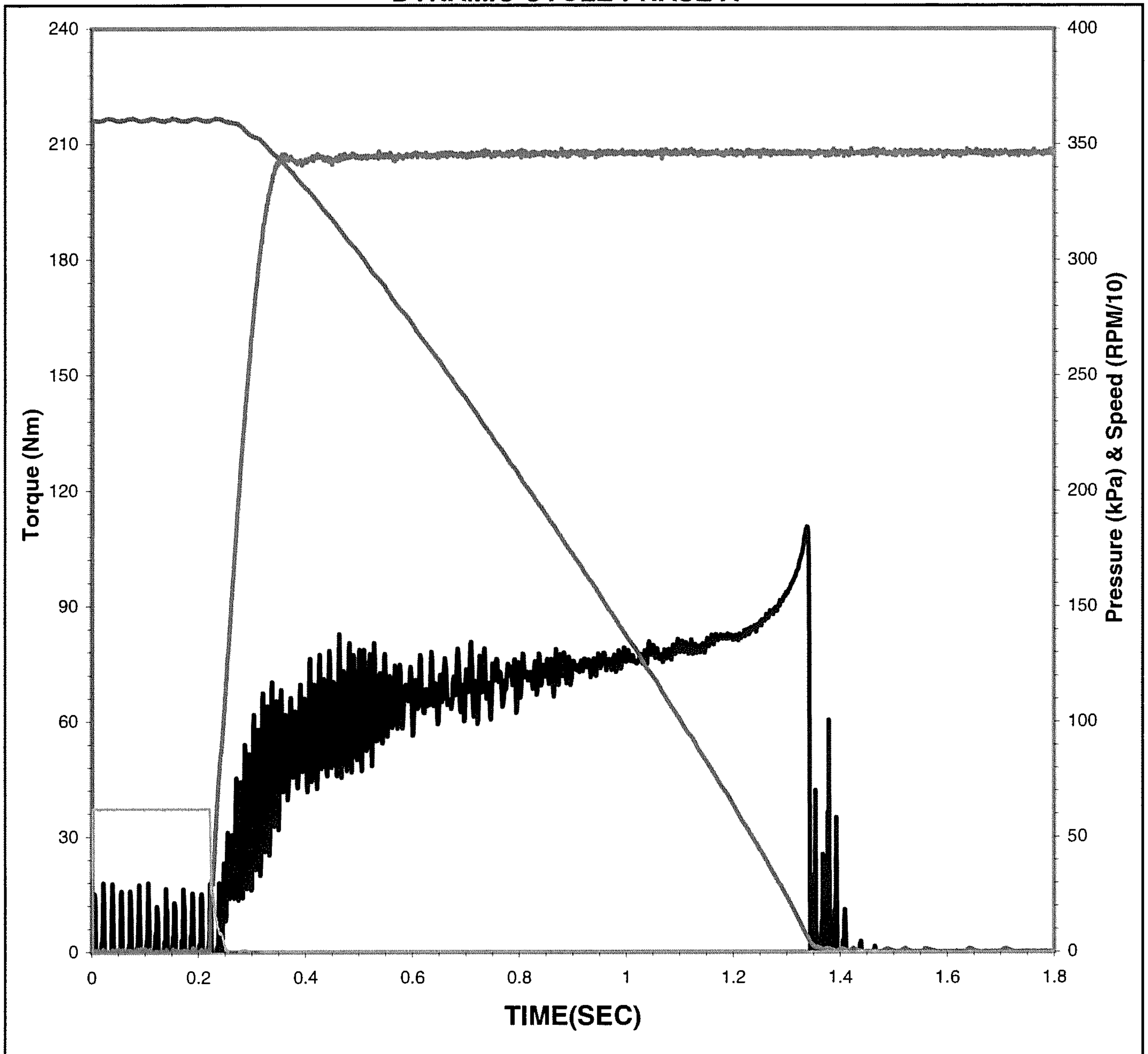
0.2 Sec Dyn:	64 N*m
Midpoint Dyn:	81 N*m
LwSpd Dynamic:	100 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.134
LwSpd Dynamic:	0.166

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	4:39:20
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	499
Temperature:	93.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.118 Sec

Torque

0.2 Sec Dyn:	60 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	110 N*m

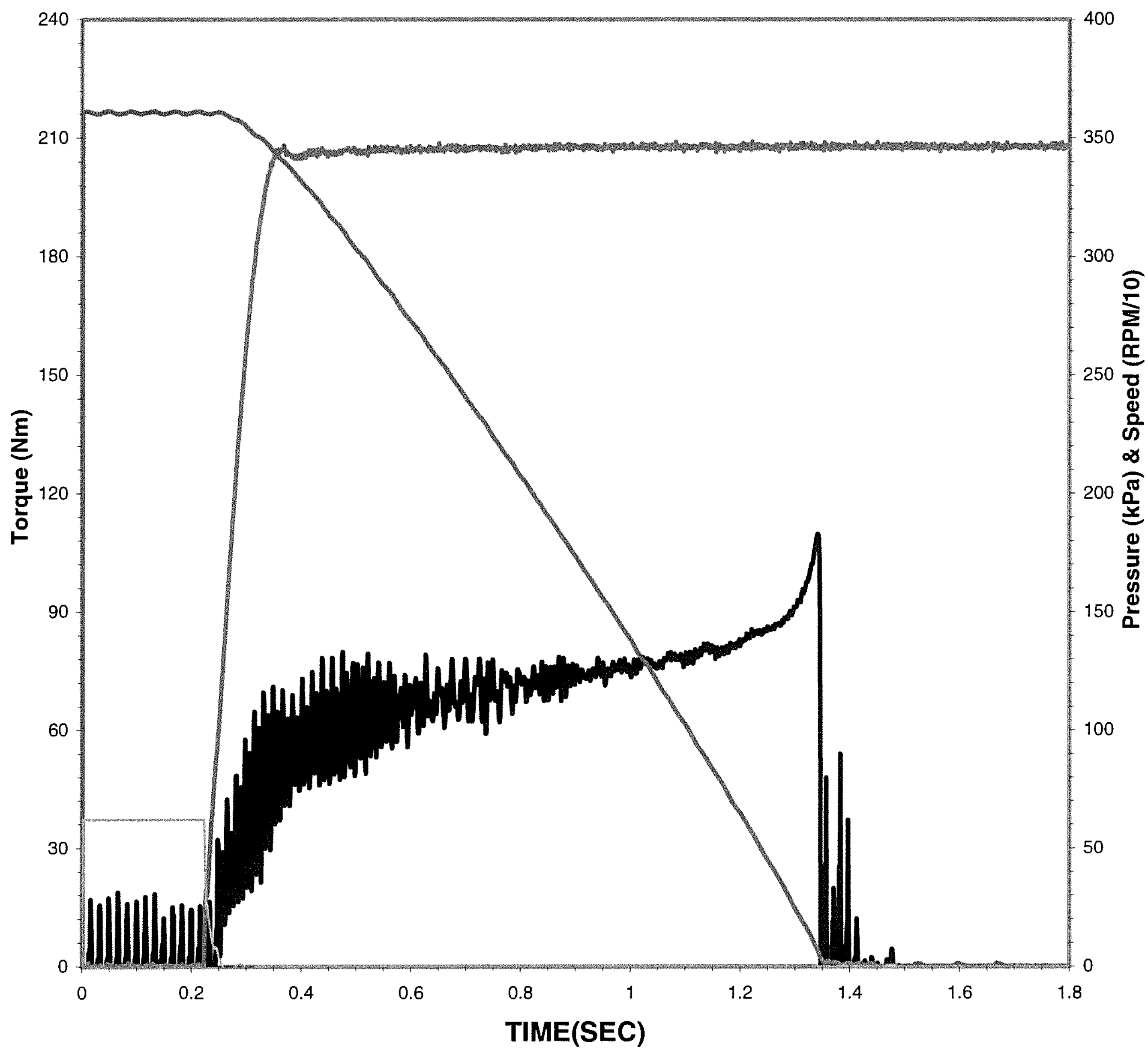
Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.183

A-10

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	4:39:35
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	500
Temperature:	93.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.122 Sec

Torque

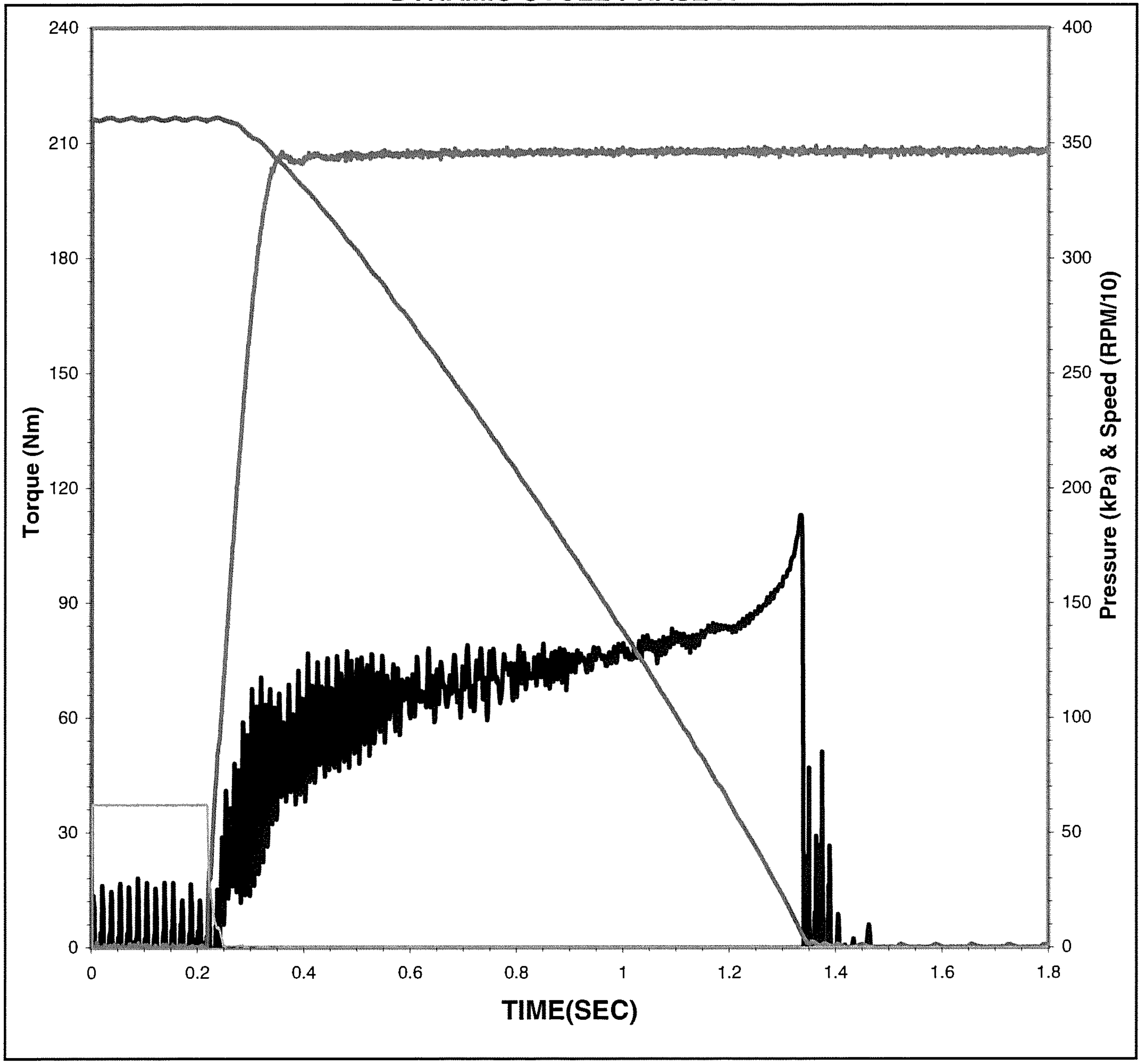
0.2 Sec Dyn:	60 N*m
Midpoint Dyn:	73 N*m
LwSpd Dynamic:	110 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.182

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	4:40:02
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	501
Temperature:	90.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.116 Sec

Torque

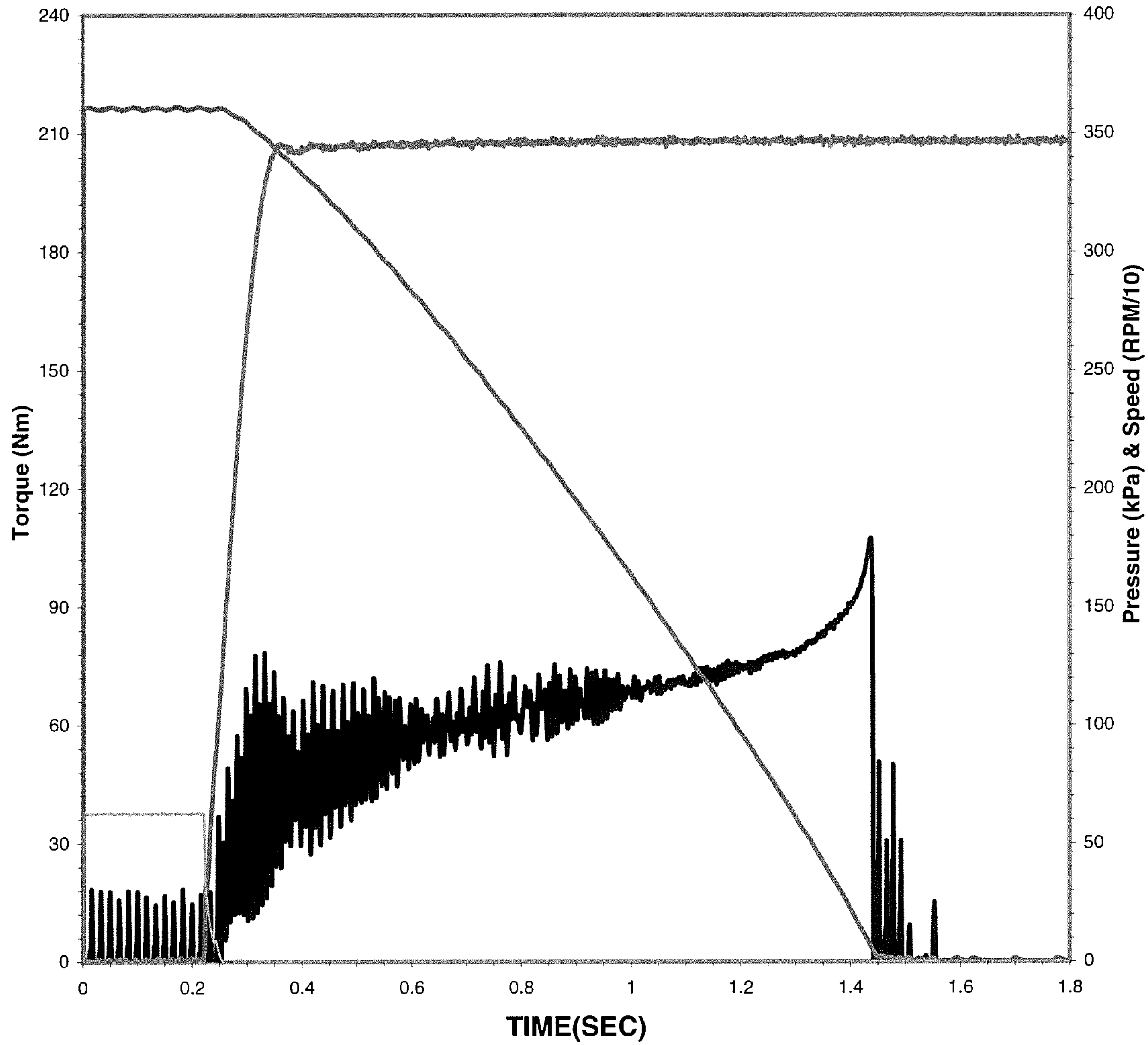
0.2 Sec Dyn:	58 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	113 N*m

Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.188

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	6:44:17
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	998
Temperature:	93.2 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	346 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.3 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.216 Sec

Torque

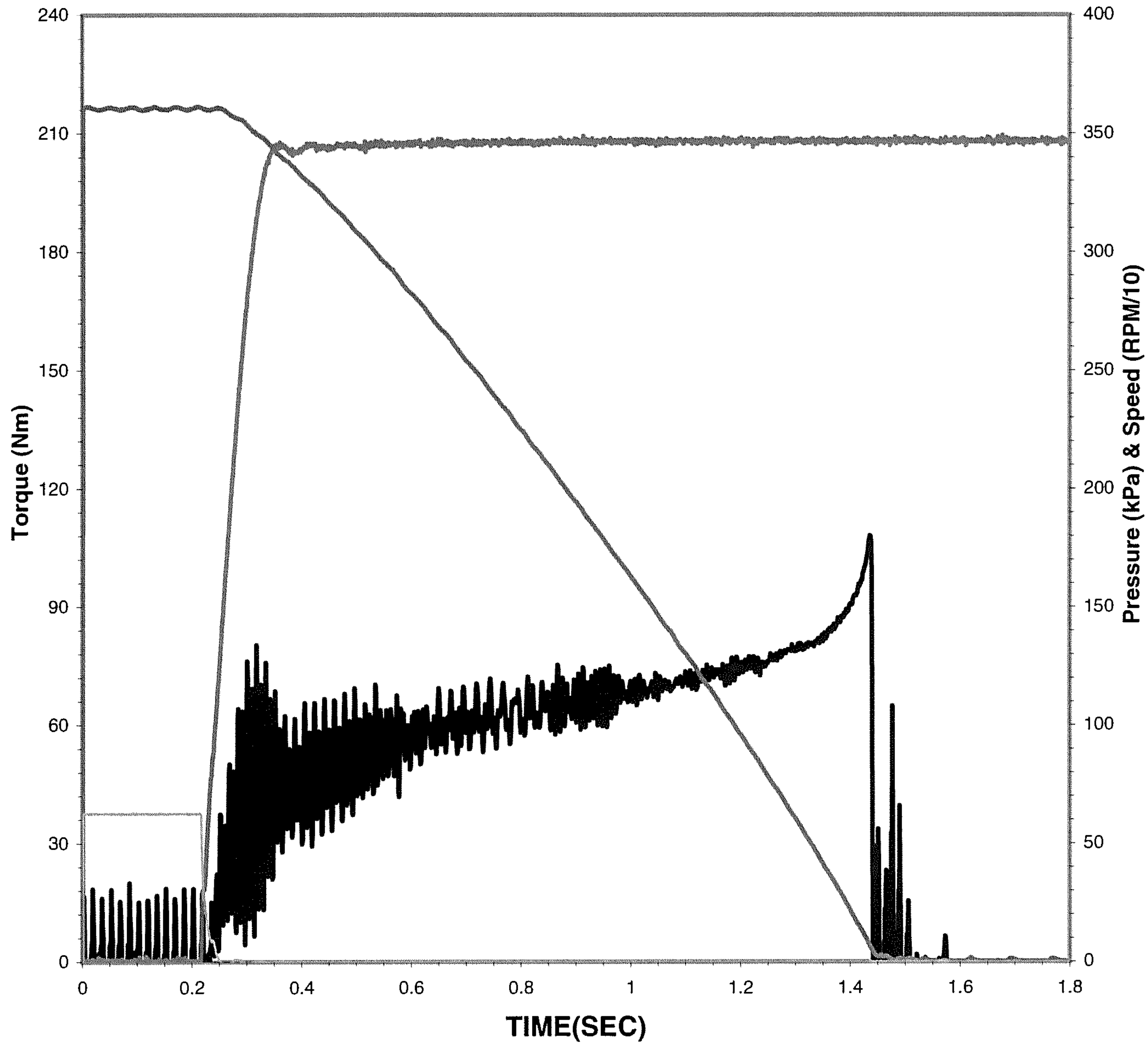
0.2 Sec Dyn:	49 N*m
Midpoint Dyn:	65 N*m
LwSpd Dynamic:	106 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.176

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	6:44:32
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	999
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.3 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.222 Sec

Torque

0.2 Sec Dyn:	49 N*m
Midpoint Dyn:	66 N*m
LwSpd Dynamic:	108 N*m

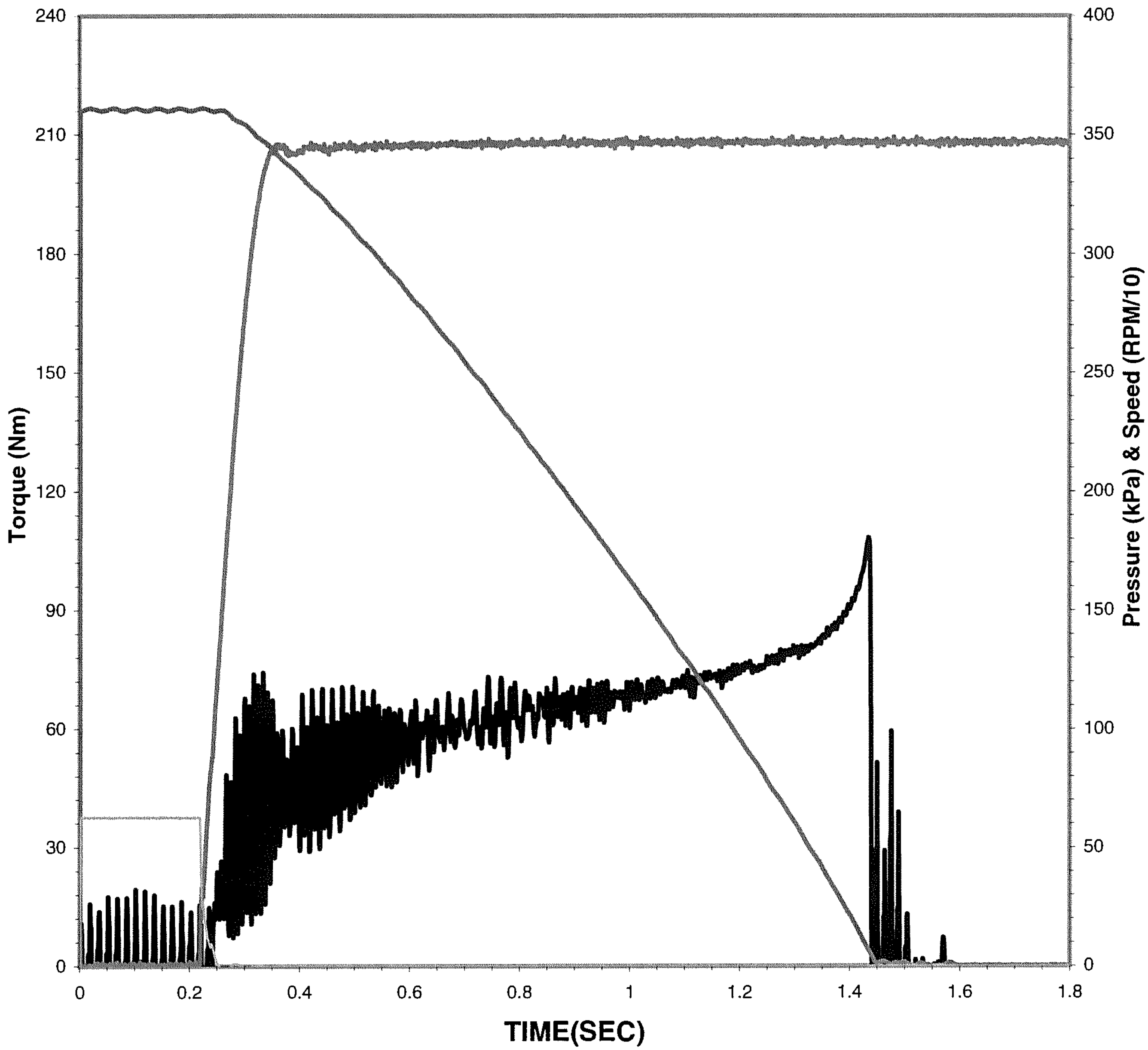
Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.179

A-14

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	1/29/2014
Time of Test:	6:44:47
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1000
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.217 Sec

Torque

0.2 Sec Dyn:	49 N*m
Midpoint Dyn:	66 N*m
LwSpd Dynamic:	108 N*m

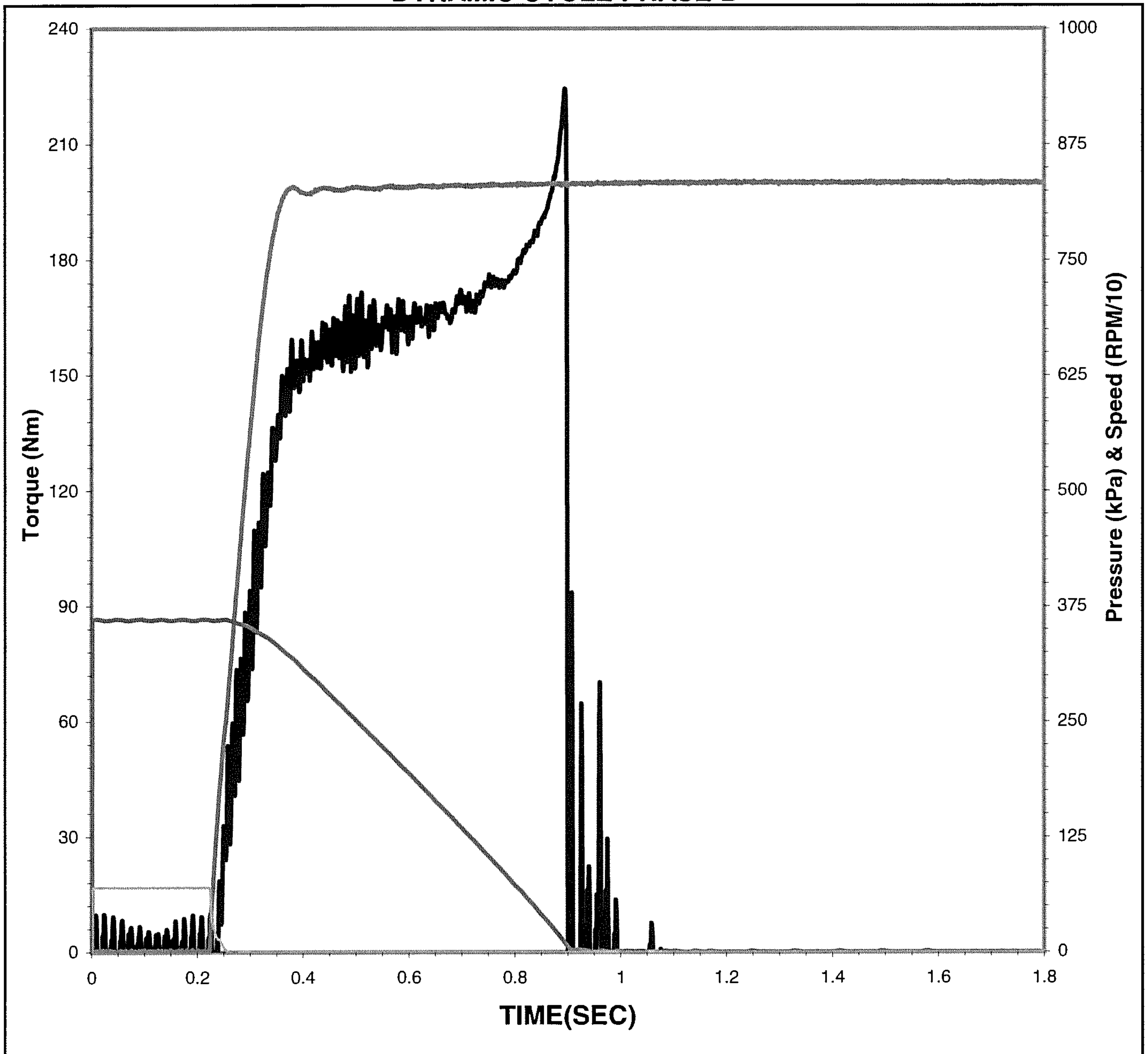
Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.178

A-15

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	6:56:28
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1010
Temperature:	91.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.677 Sec

Torque

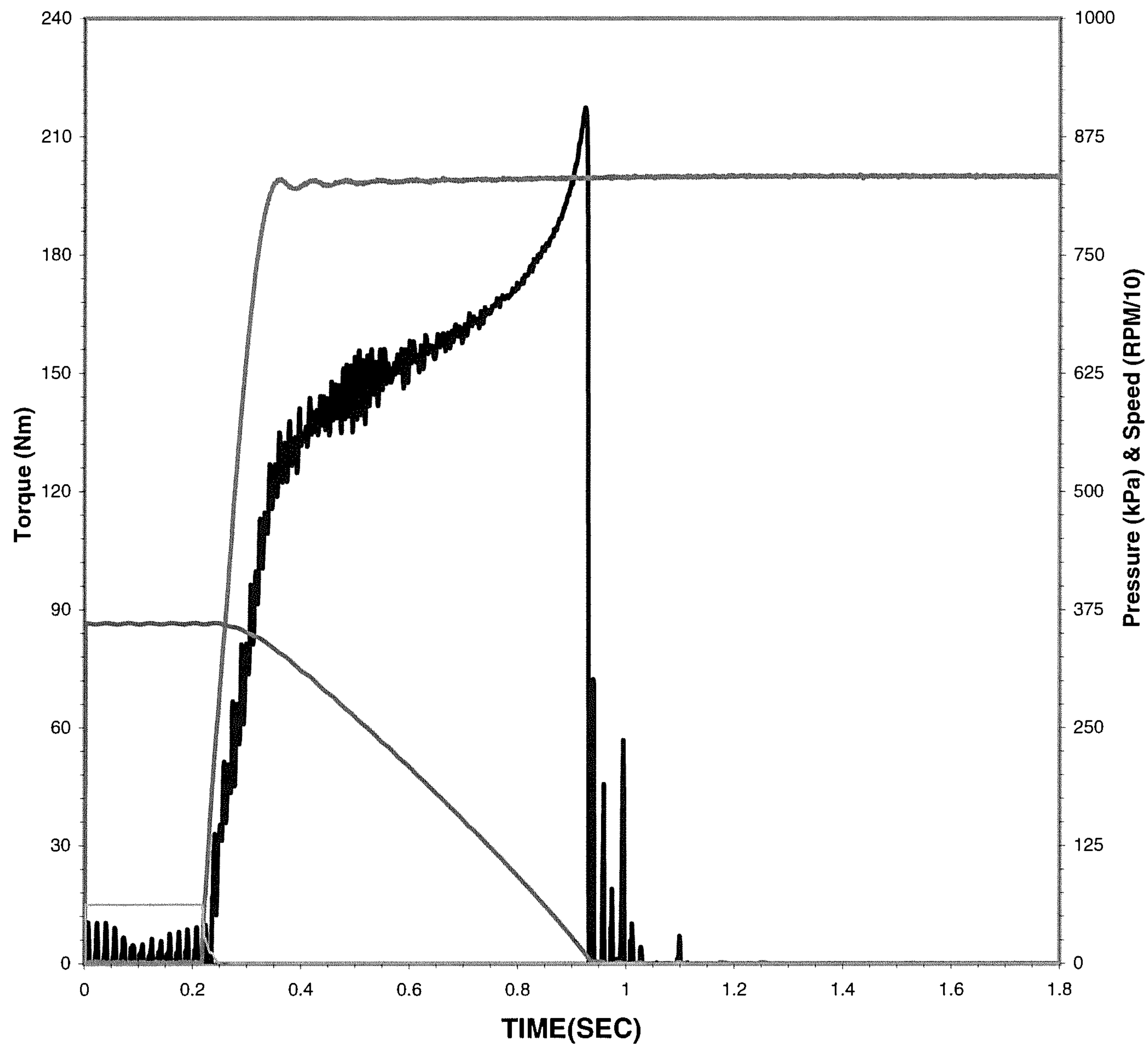
0.2 Sec Dyn:	157 N*m
Midpoint Dyn:	163 N*m
LwSpd Dynamic:	224 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.155

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	8:58:43
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1499
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.714 Sec

Torque

0.2 Sec Dyn:	139 N*m
Midpoint Dyn:	153 N*m
LwSpd Dynamic:	214 N*m

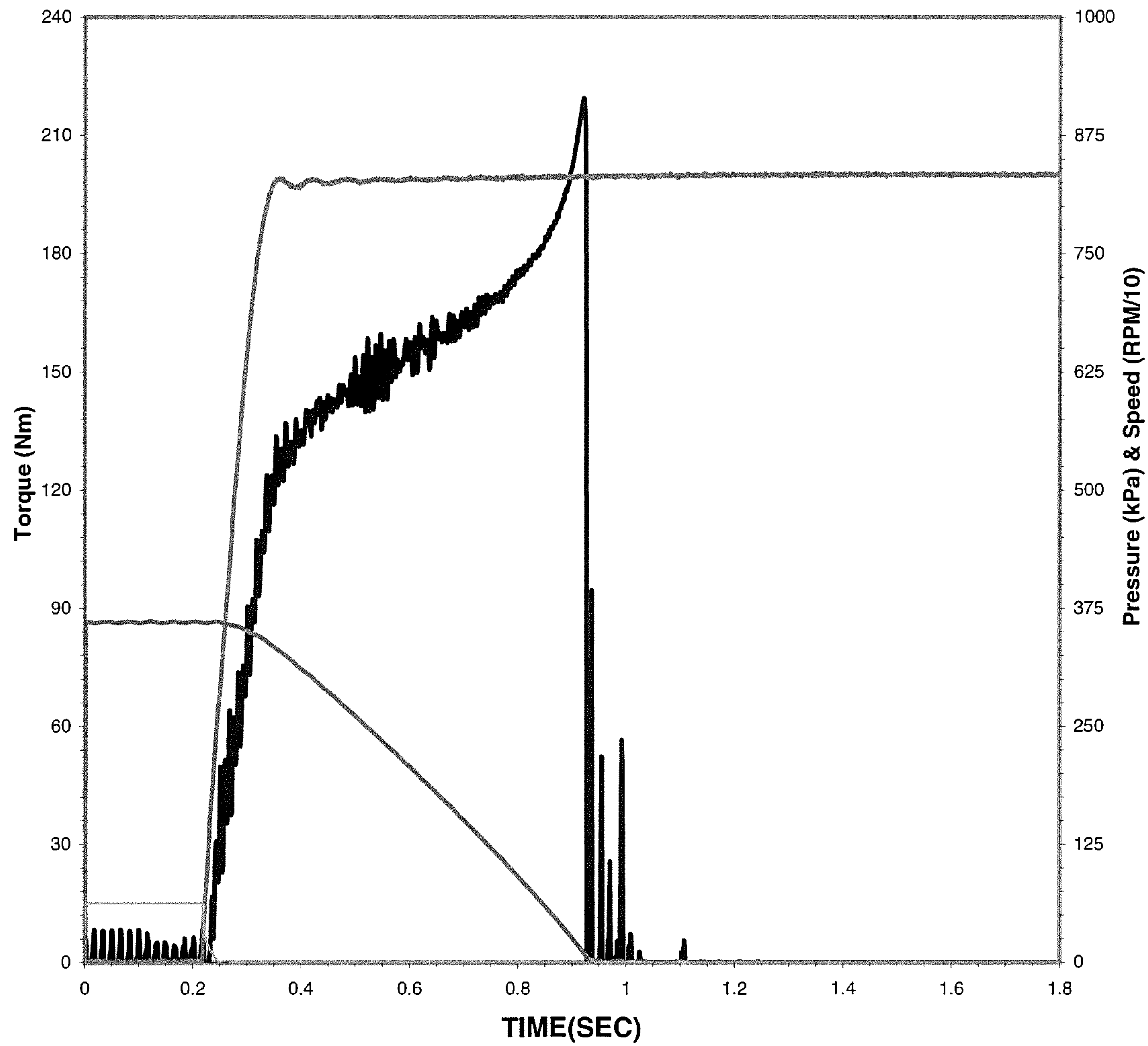
Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.148

A-17

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	8:58:58
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1500
Temperature:	111.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.71 Sec

Torque

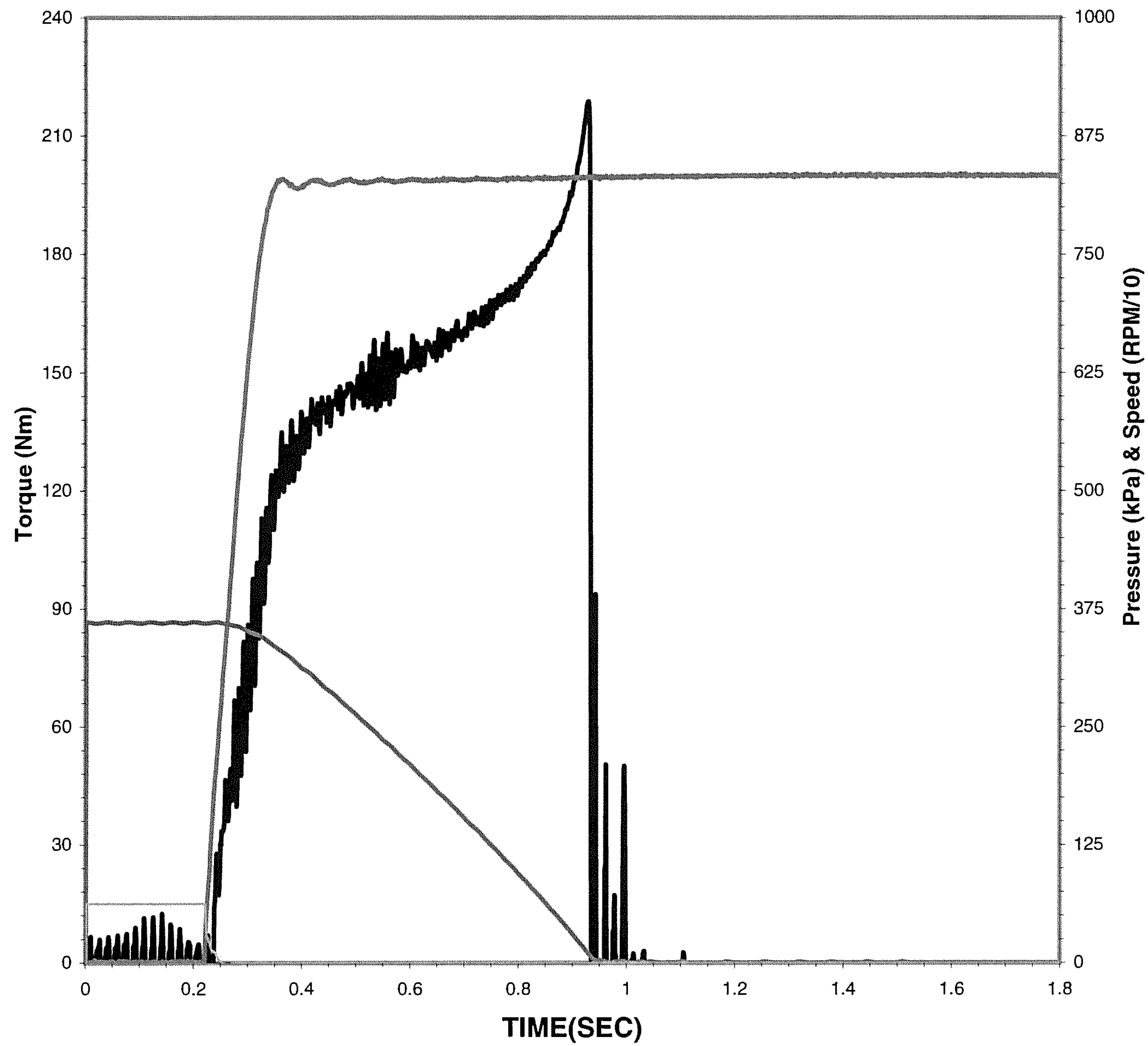
0.2 Sec Dyn:	139 N*m
Midpoint Dyn:	153 N*m
LwSpd Dynamic:	214 N*m

Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.106
LwSpd Dynamic:	0.148

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	8:59:25
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1501
Temperature:	106.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.714 Sec

Torque

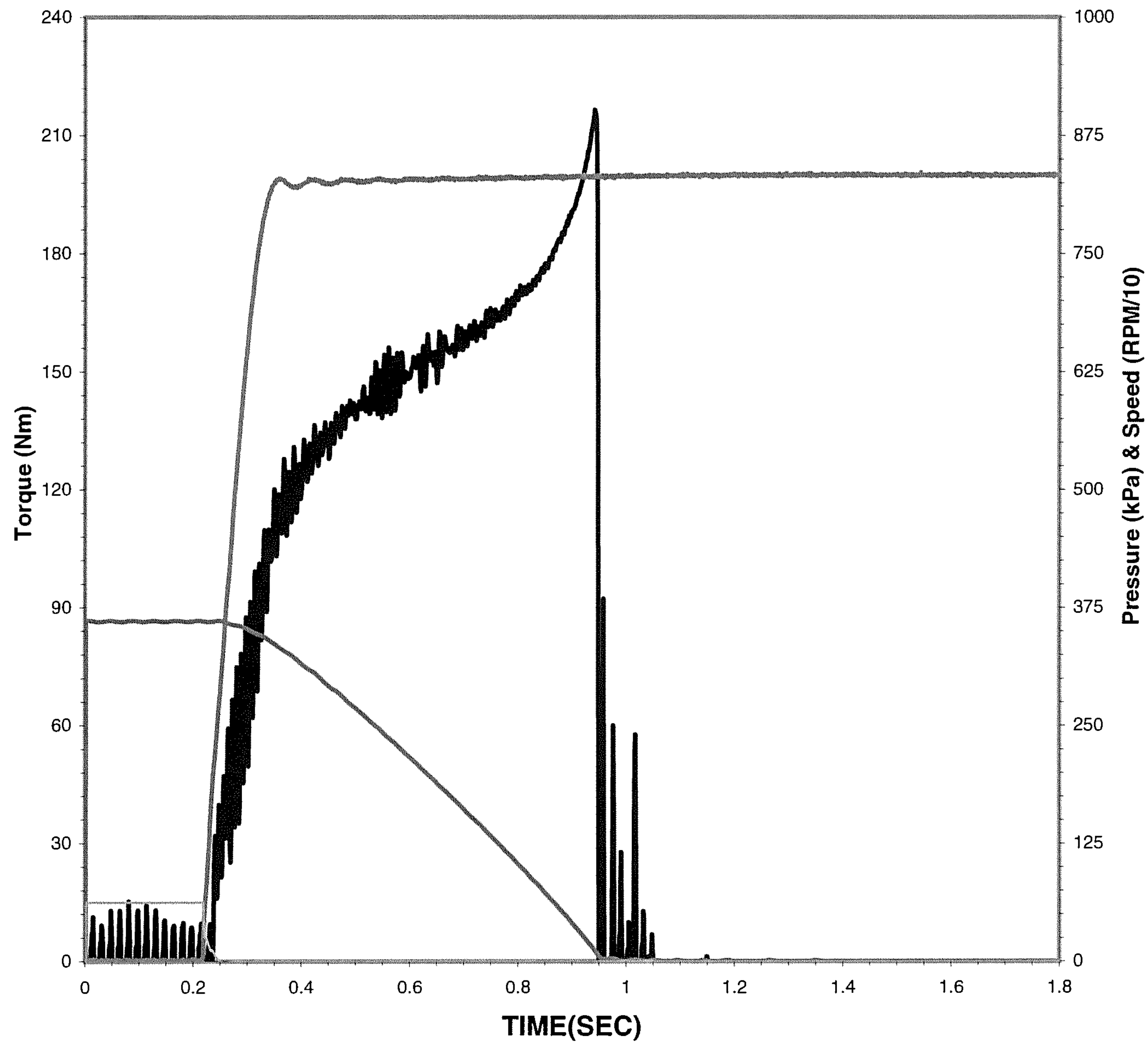
0.2 Sec Dyn:	140 N*m
Midpoint Dyn:	152 N*m
LwSpd Dynamic:	214 N*m

Coefficient of Friction

.2 Sec Dyn:	0.097
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.148

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	11:03:55
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	1999
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.732 Sec

Torque

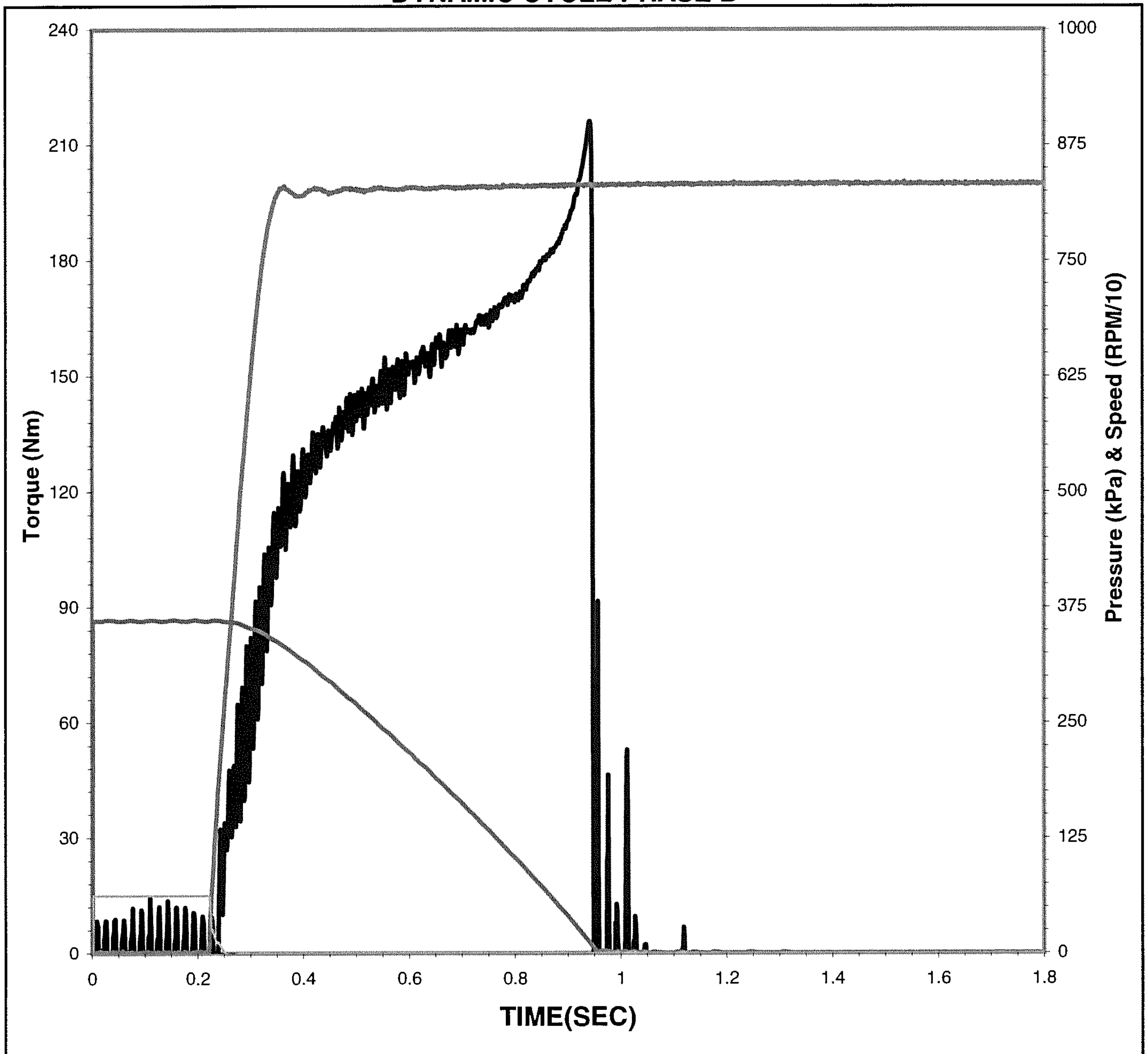
0.2 Sec Dyn:	130 N*m
Midpoint Dyn:	150 N*m
LwSpd Dynamic:	210 N*m

Coefficient of Friction

.2 Sec Dyn:	0.090
Midpoint Dyn:	0.104
LwSpd Dynamic:	0.145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	11:04:10
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2000
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.727 Sec

Torque

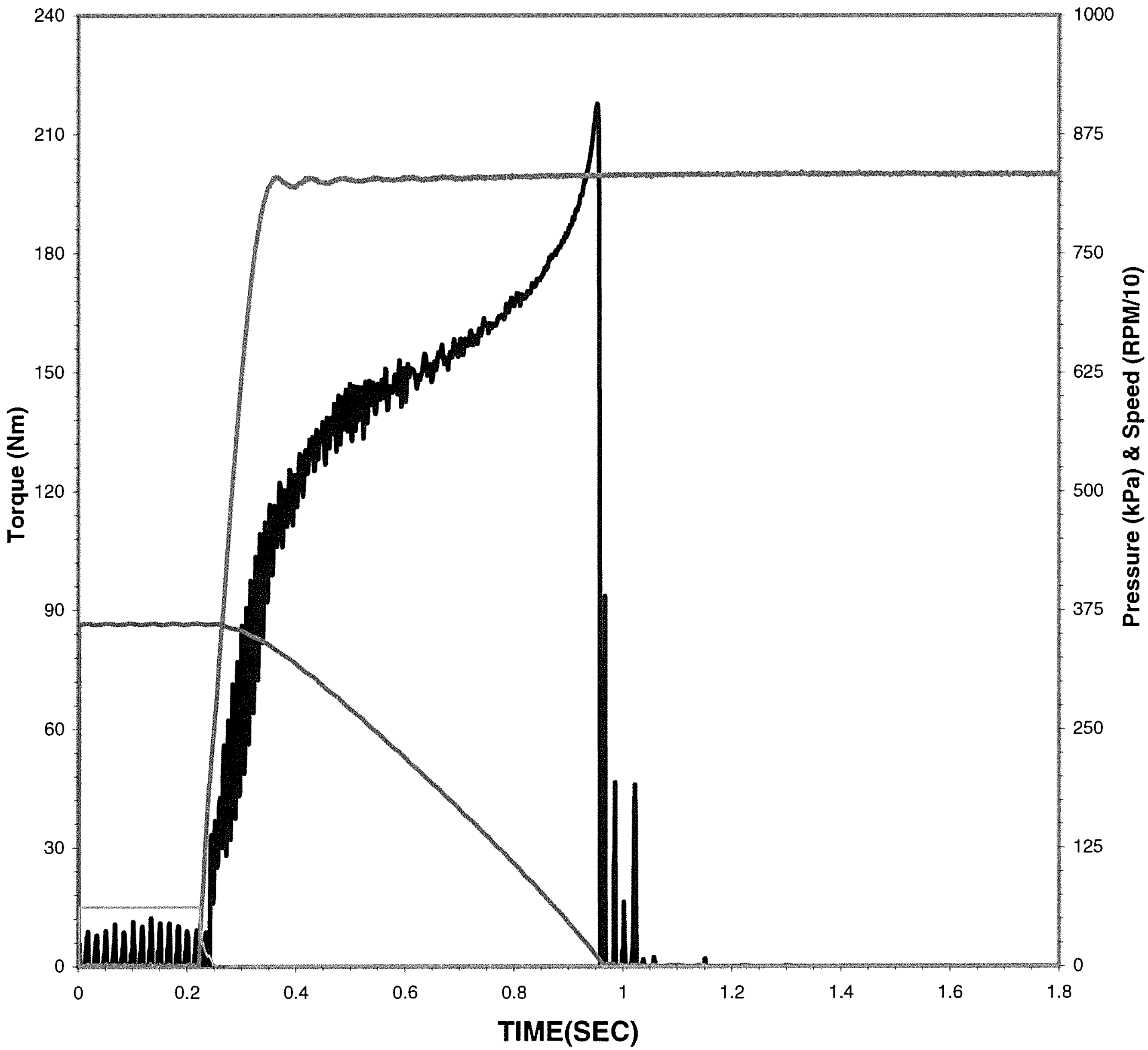
0.2 Sec Dyn:	132 N*m
Midpoint Dyn:	152 N*m
LwSpd Dynamic:	210 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	11:04:37
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2001
Temperature:	107.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.736 Sec

Torque

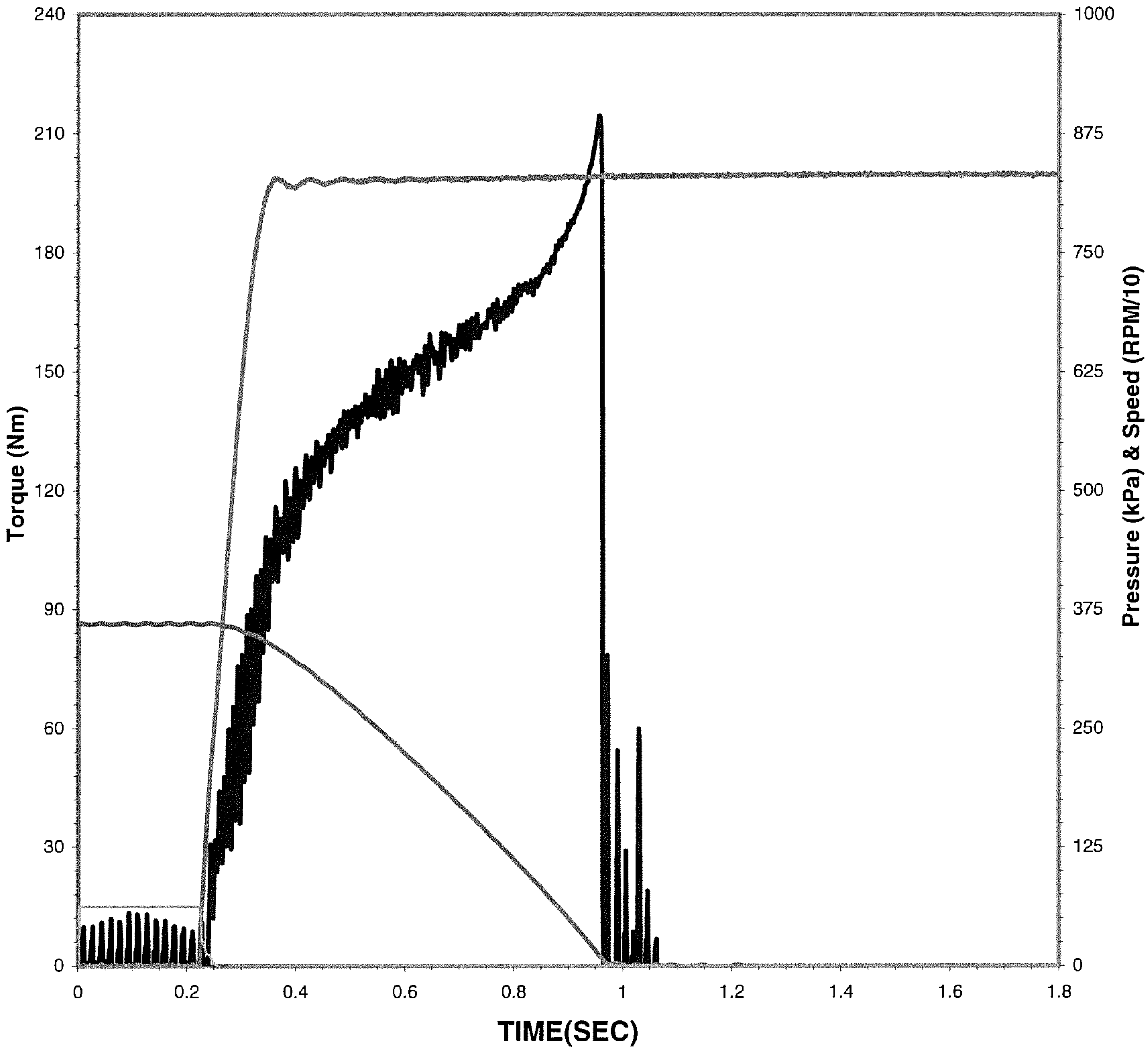
0.2 Sec Dyn:	131 N*m
Midpoint Dyn:	149 N*m
LwSpd Dynamic:	213 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.103
LwSpd Dynamic:	0.147

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	13:09:07
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2499
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.741 Sec

Torque

0.2 Sec Dyn:	125 N*m
Midpoint Dyn:	149 N*m
LwSpd Dynamic:	212 N*m

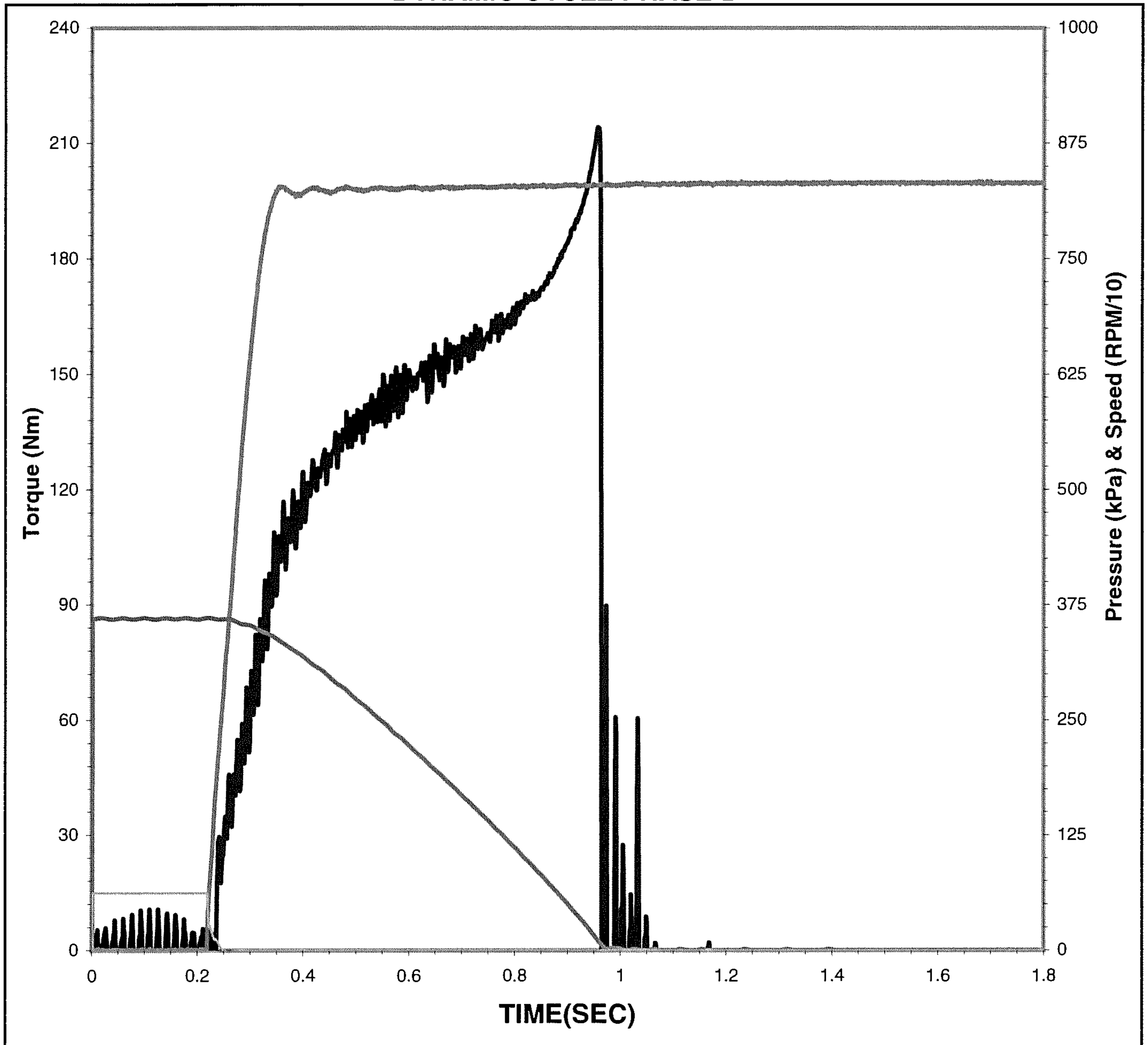
Coefficient of Friction

.2 Sec Dyn:	0.087
Midpoint Dyn:	0.103
LwSpd Dynamic:	0.147

A-23

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	13:09:22
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2500
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.746 Sec

Torque

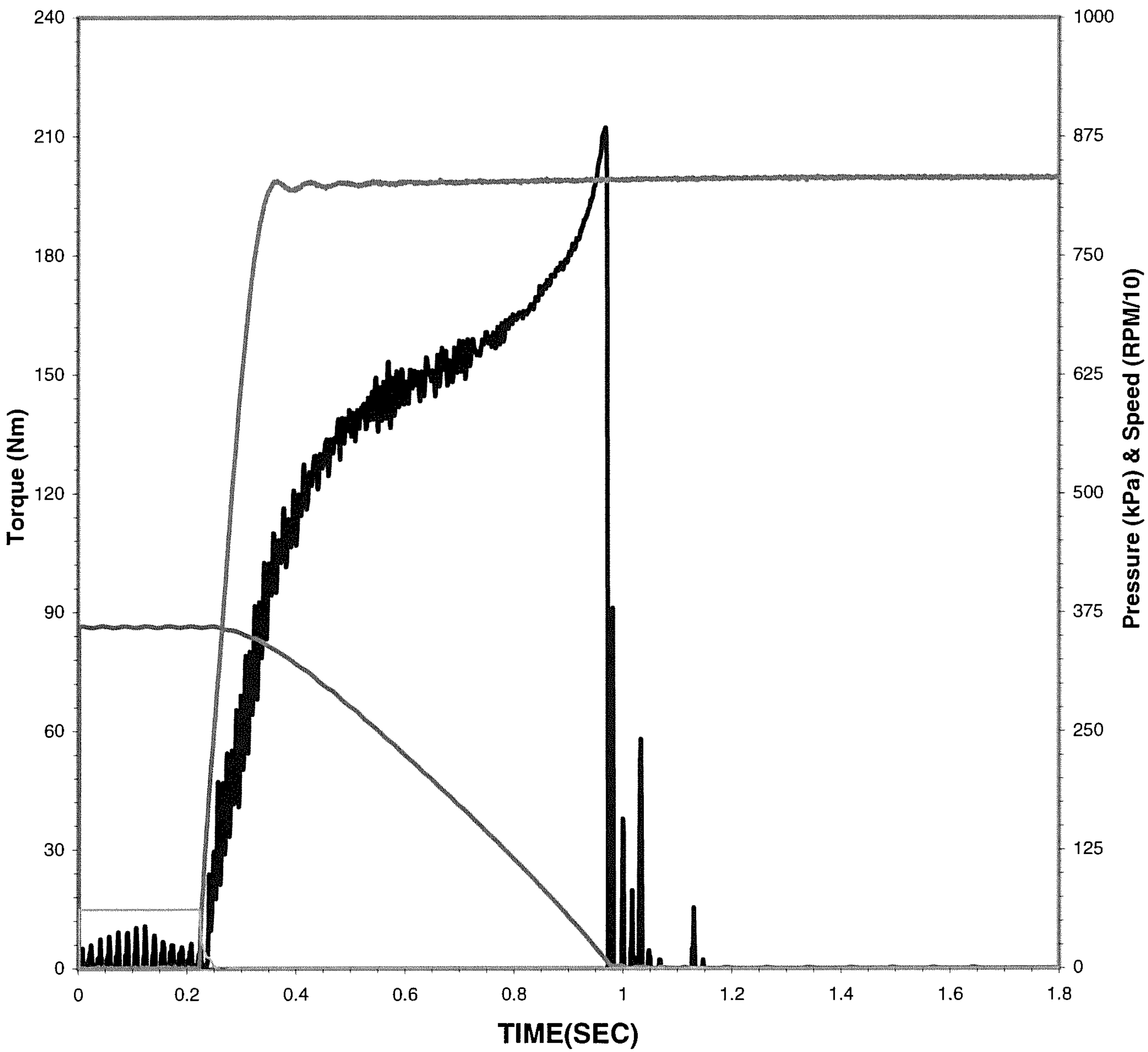
0.2 Sec Dyn:	124 N*m
Midpoint Dyn:	148 N*m
LwSpd Dynamic:	209 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	13:09:48
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2501
Temperature:	106.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.75 Sec

Torque

0.2 Sec Dyn:	123 N*m
Midpoint Dyn:	148 N*m
LwSpd Dynamic:	211 N*m

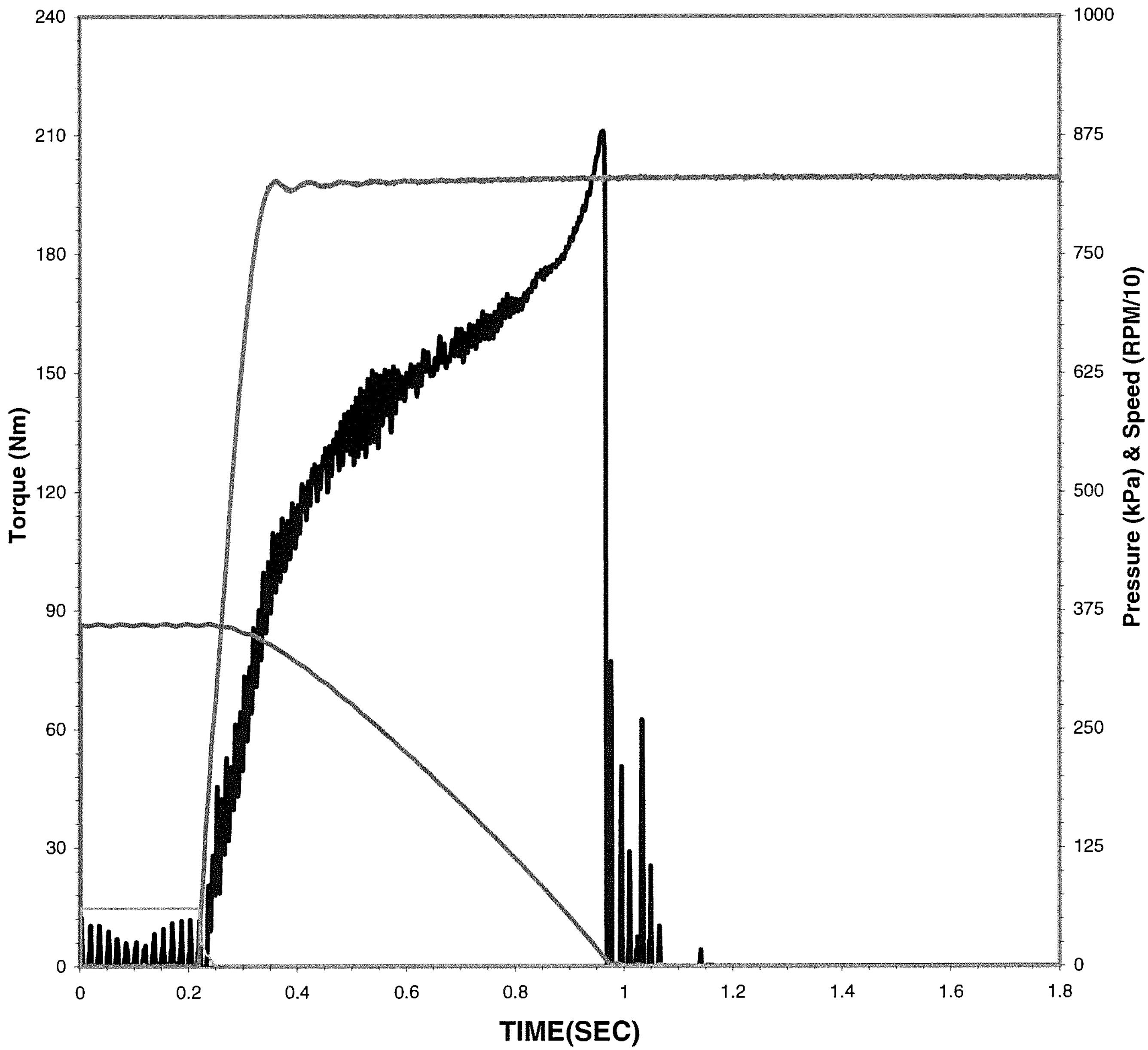
Coefficient of Friction

.2 Sec Dyn:	0.085
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.146

A-25

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	15:14:18
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	2999
Temperature:	110.9 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	826 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.5 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.75 Sec

Torque

0.2 Sec Dyn:	121 N*m
Midpoint Dyn:	148 N*m
LwSpd Dynamic:	209 N*m

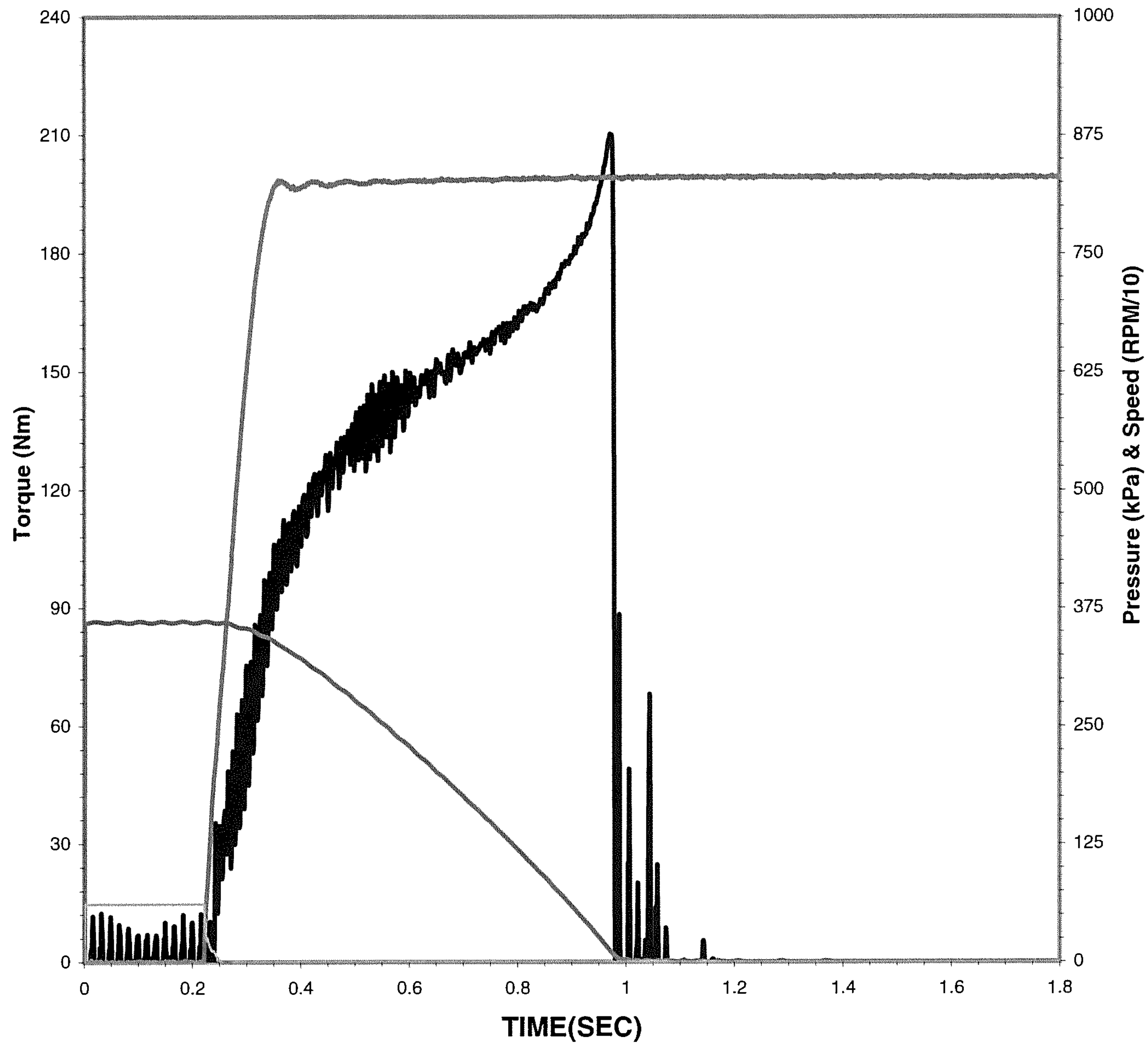
Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.144

A-26

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	15:14:34
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	3000
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.758 Sec

Torque

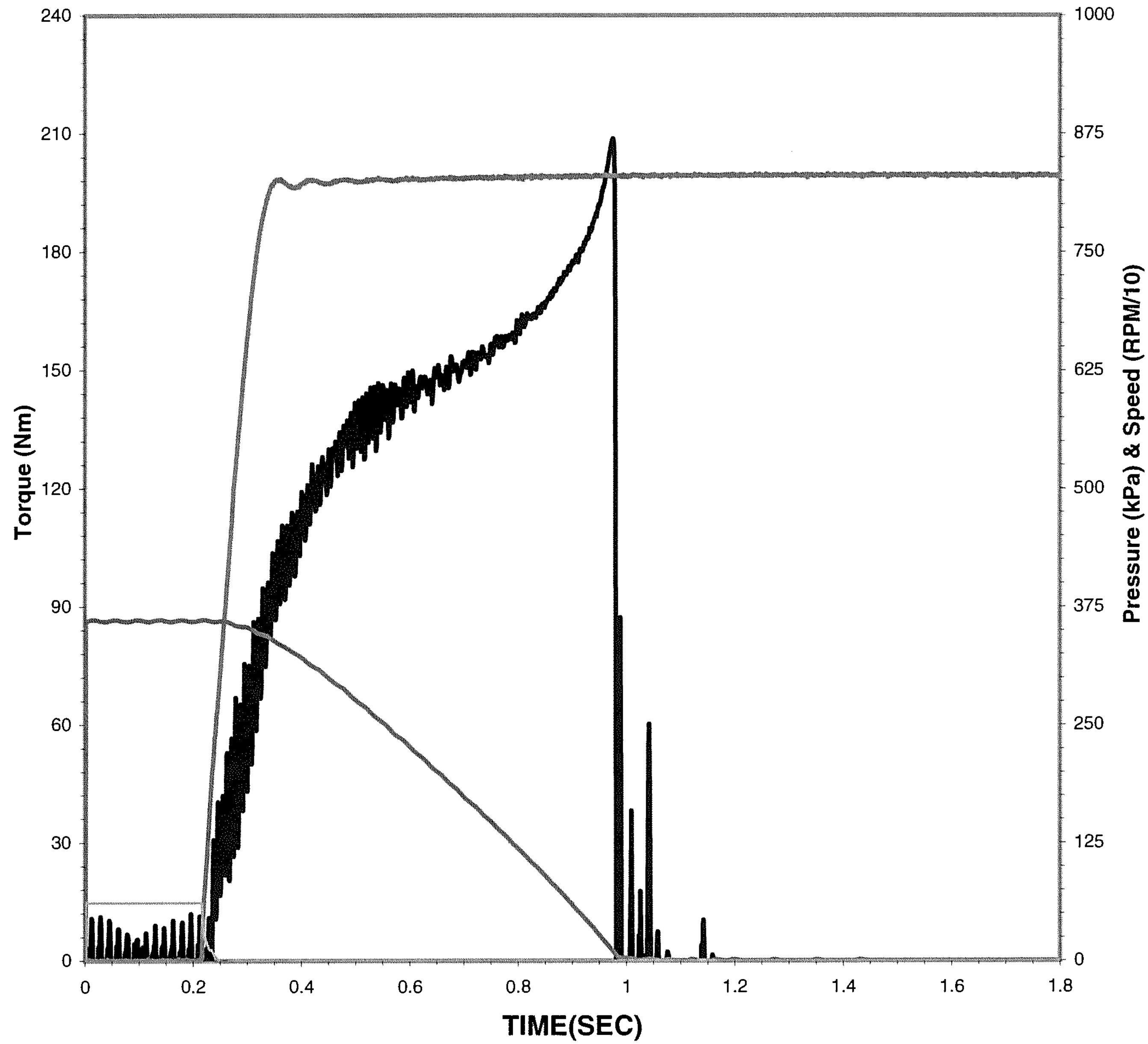
0.2 Sec Dyn:	121 N*m
Midpoint Dyn:	146 N*m
LwSpd Dynamic:	209 N*m

Coefficient of Friction

.2 Sec Dyn:	0.083
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**1/29/2014**
Time of Test:	**15:15:00**
Test Number:	**C4-9-1449**
Fluid Code:	**LO292039**
Cycle Number:	**3001**
Temperature:	**107.2 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**827 kPa** 827 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.765 Sec**

Torque

0.2 Sec Dyn:	**120 N*m**
Midpoint Dyn:	**146 N*m**
LwSpd Dynamic:	**207 N*m**

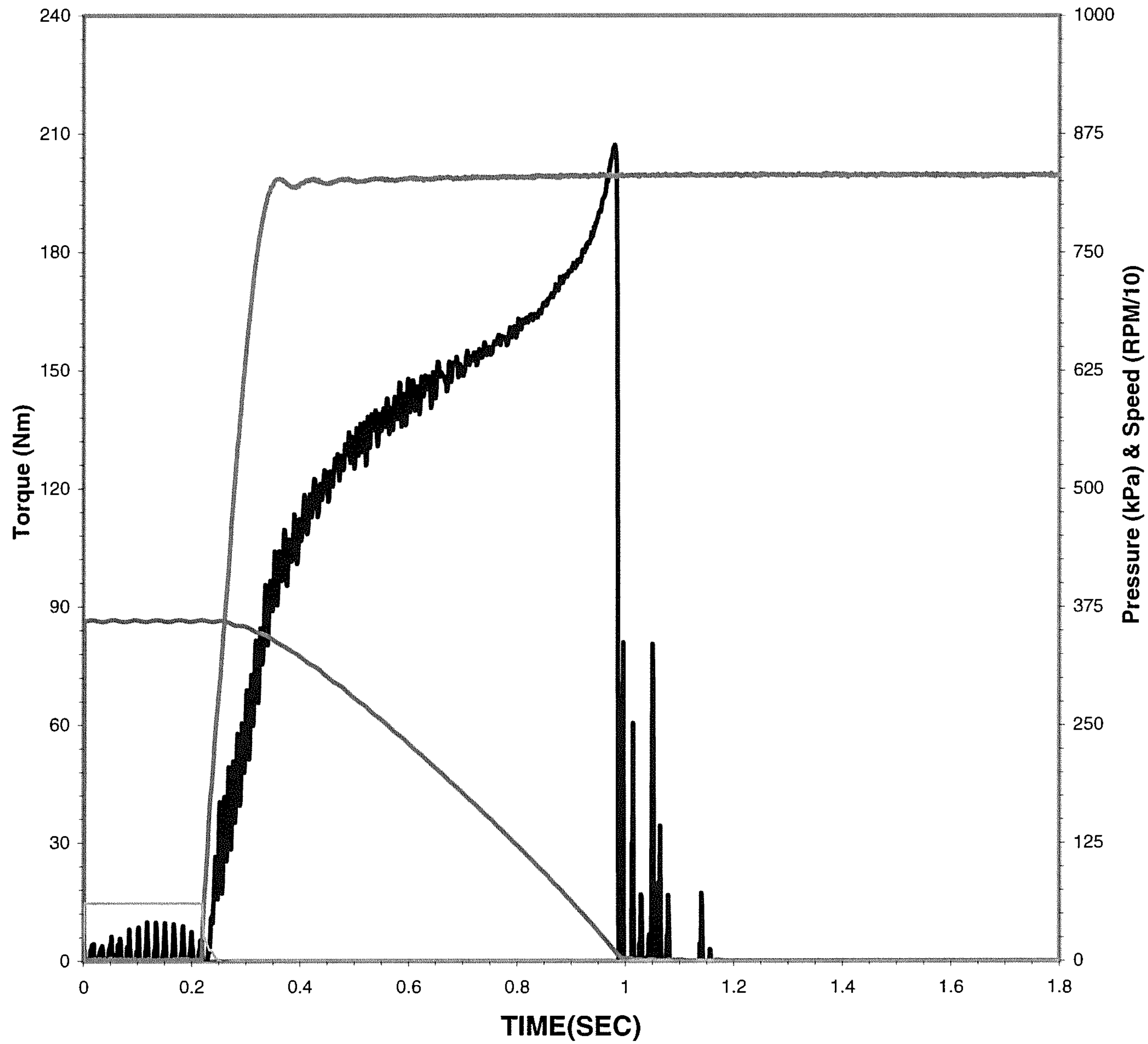
Coefficient of Friction

.2 Sec Dyn:	**0.083**
Midpoint Dyn:	**0.101**
LwSpd Dynamic:	**0.143**

A-28

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	17:19:30
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	3499
Temperature:	111.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.769 Sec

Torque

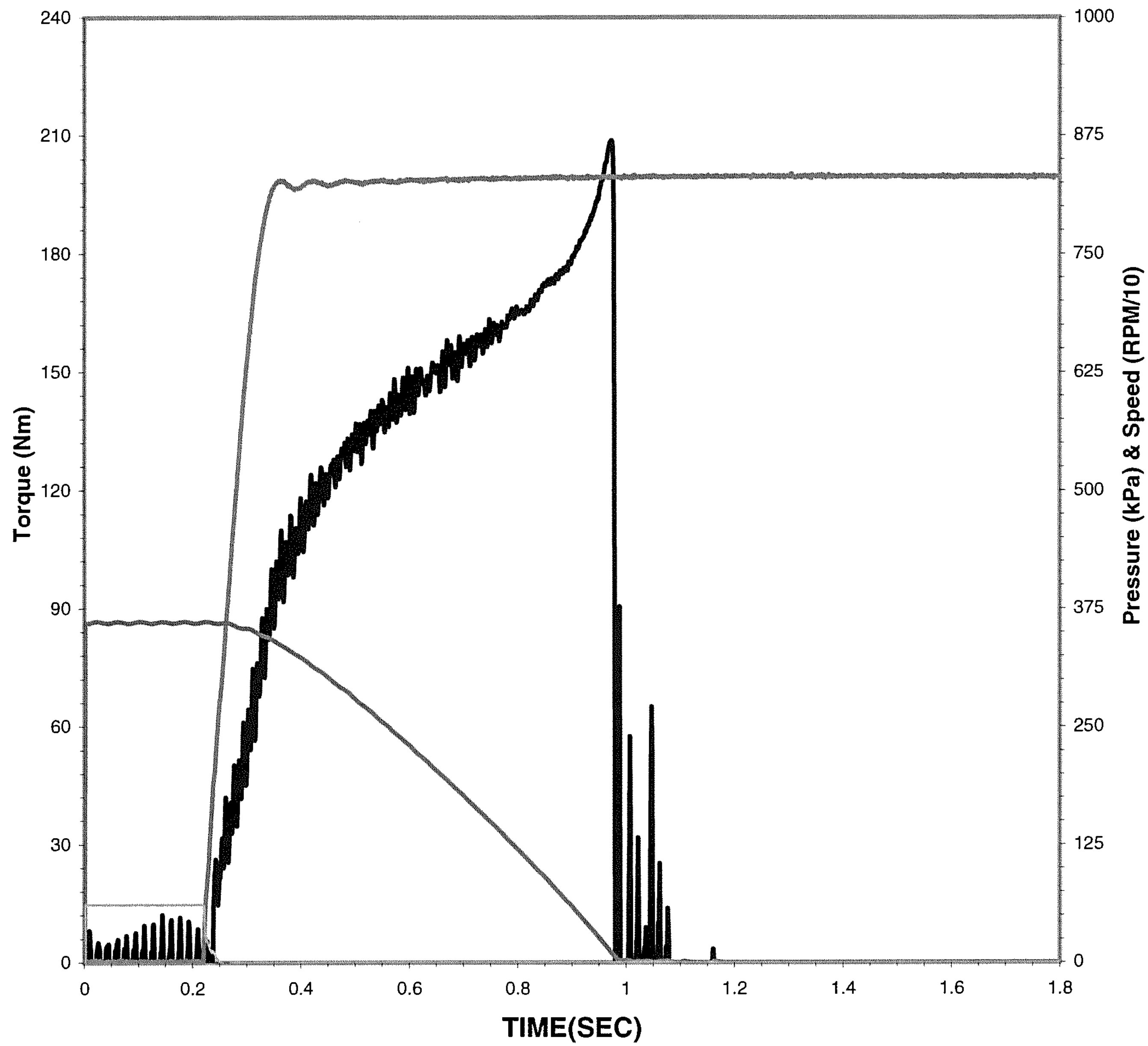
0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	144 N*m
LwSpd Dynamic:	204 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.141

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	17:19:45
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	3500
Temperature:	111.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.759 Sec

Torque

0.2 Sec Dyn:	119 N*m
Midpoint Dyn:	146 N*m
LwSpd Dynamic:	204 N*m

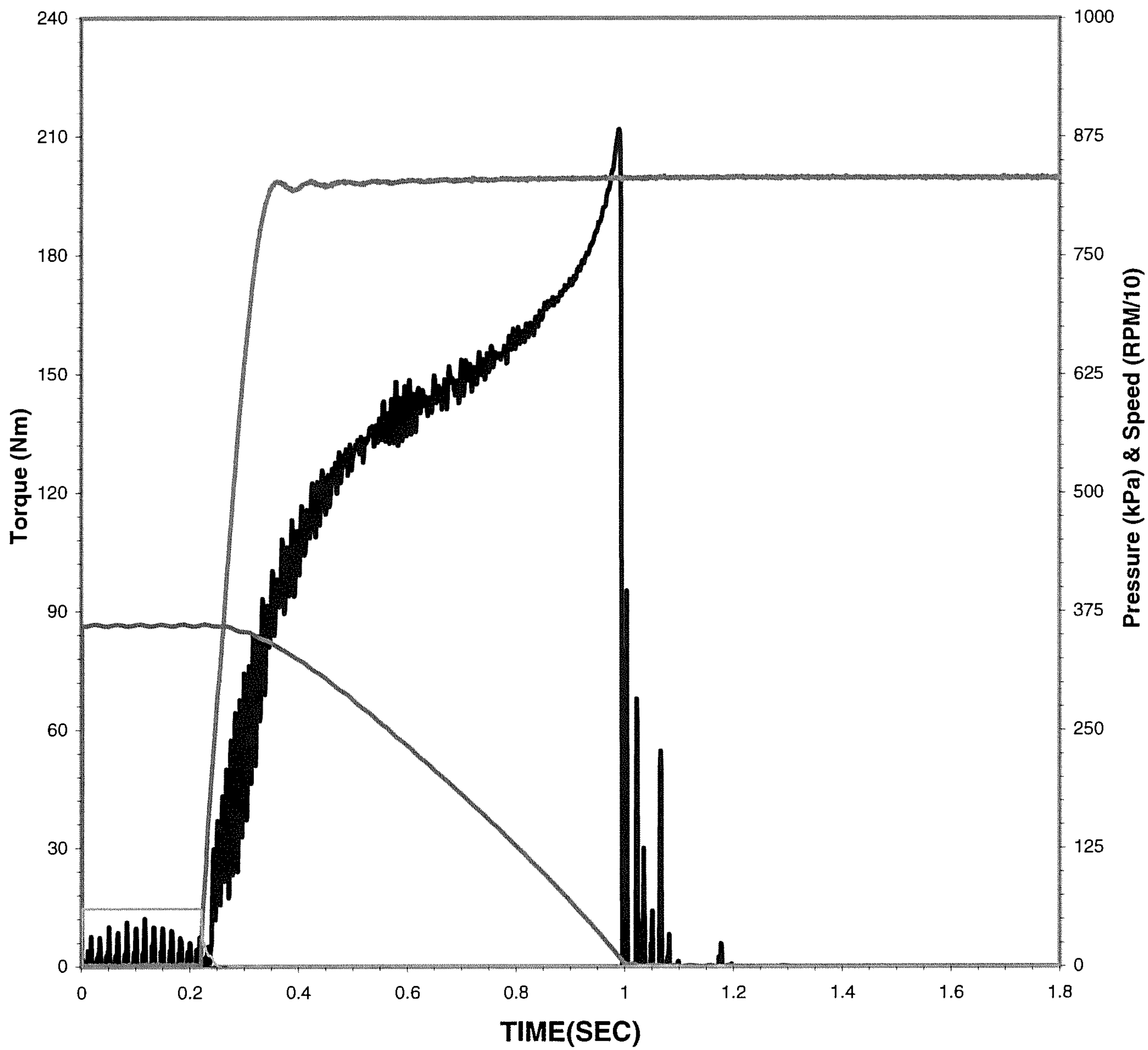
Coefficient of Friction

.2 Sec Dyn:	0.082
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.141

A-30

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	17:20:12
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	3501
Temperature:	107.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.775 Sec

Torque

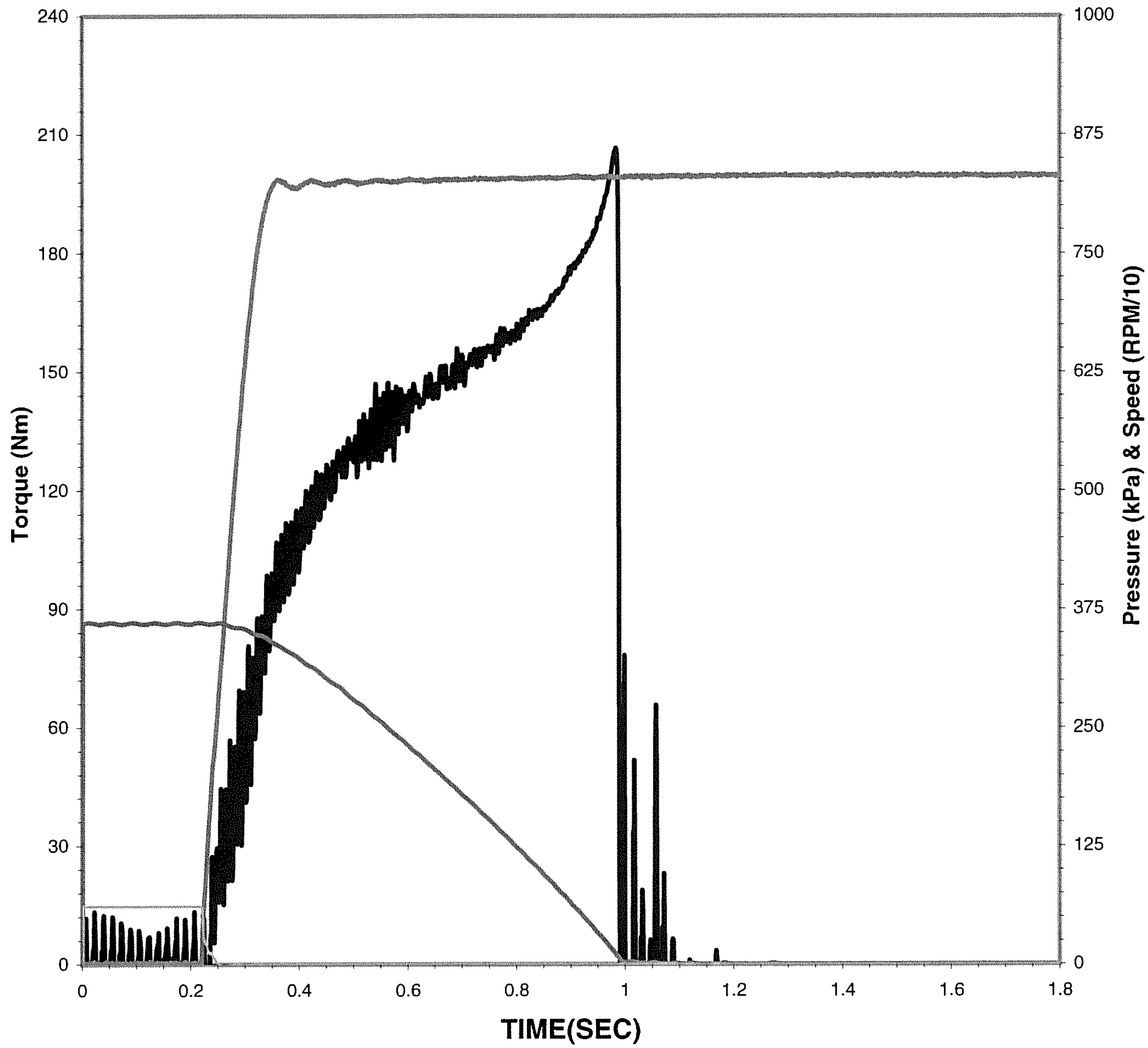
0.2 Sec Dyn:	116 N*m
Midpoint Dyn:	142 N*m
LwSpd Dynamic:	209 N*m

Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.098
LwSpd Dynamic:	0.144

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	19:24:42
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	3999
Temperature:	111.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.77 Sec

Torque

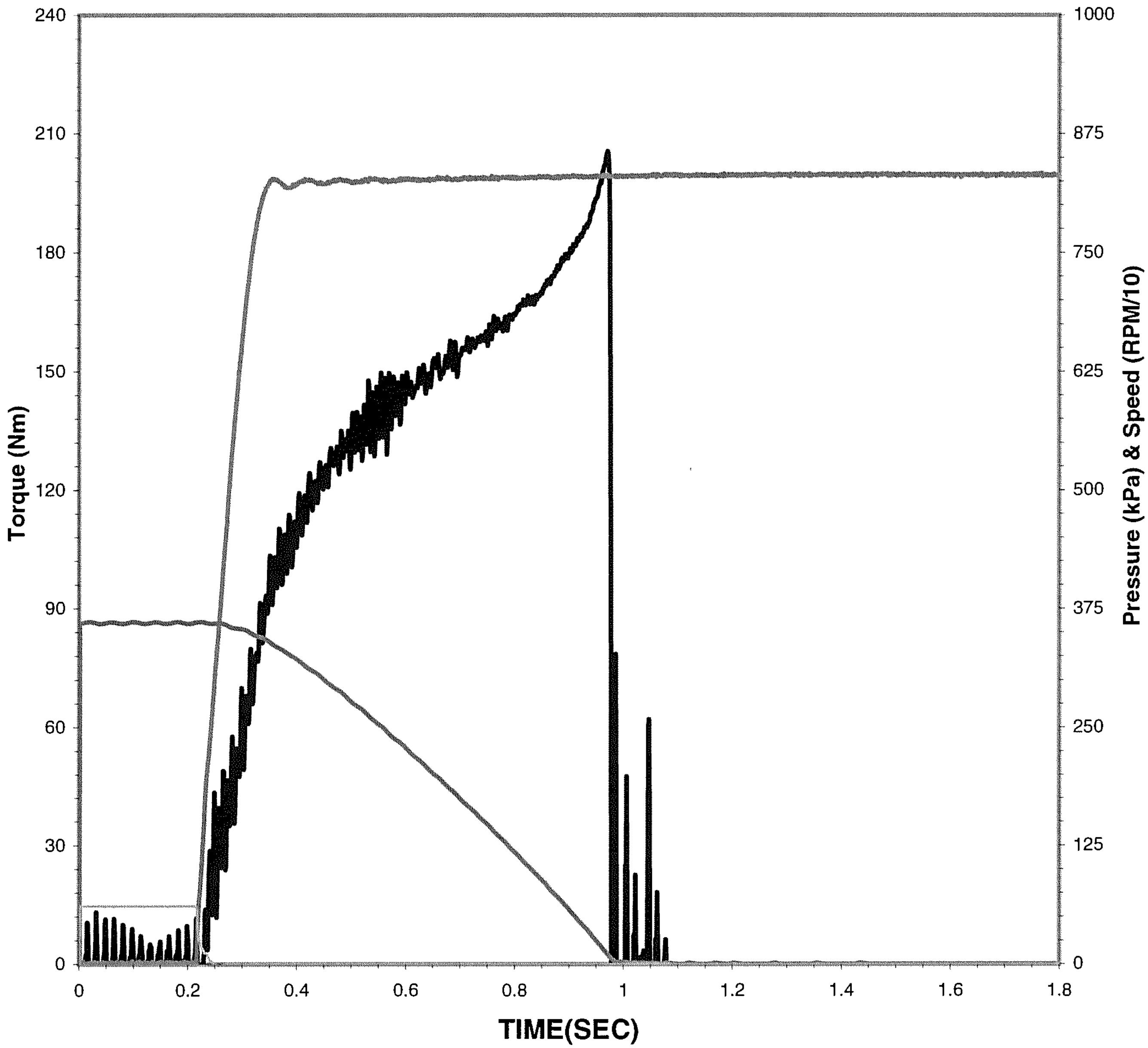
0.2 Sec Dyn:	116 N*m
Midpoint Dyn:	143 N*m
LwSpd Dynamic:	203 N*m

Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.141

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	19:24:57
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4000
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.761 Sec

Torque

0.2 Sec Dyn:	118 N*m
Midpoint Dyn:	146 N*m
LwSpd Dynamic:	200 N*m

Coefficient of Friction

.2 Sec Dyn:	0.082
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.138

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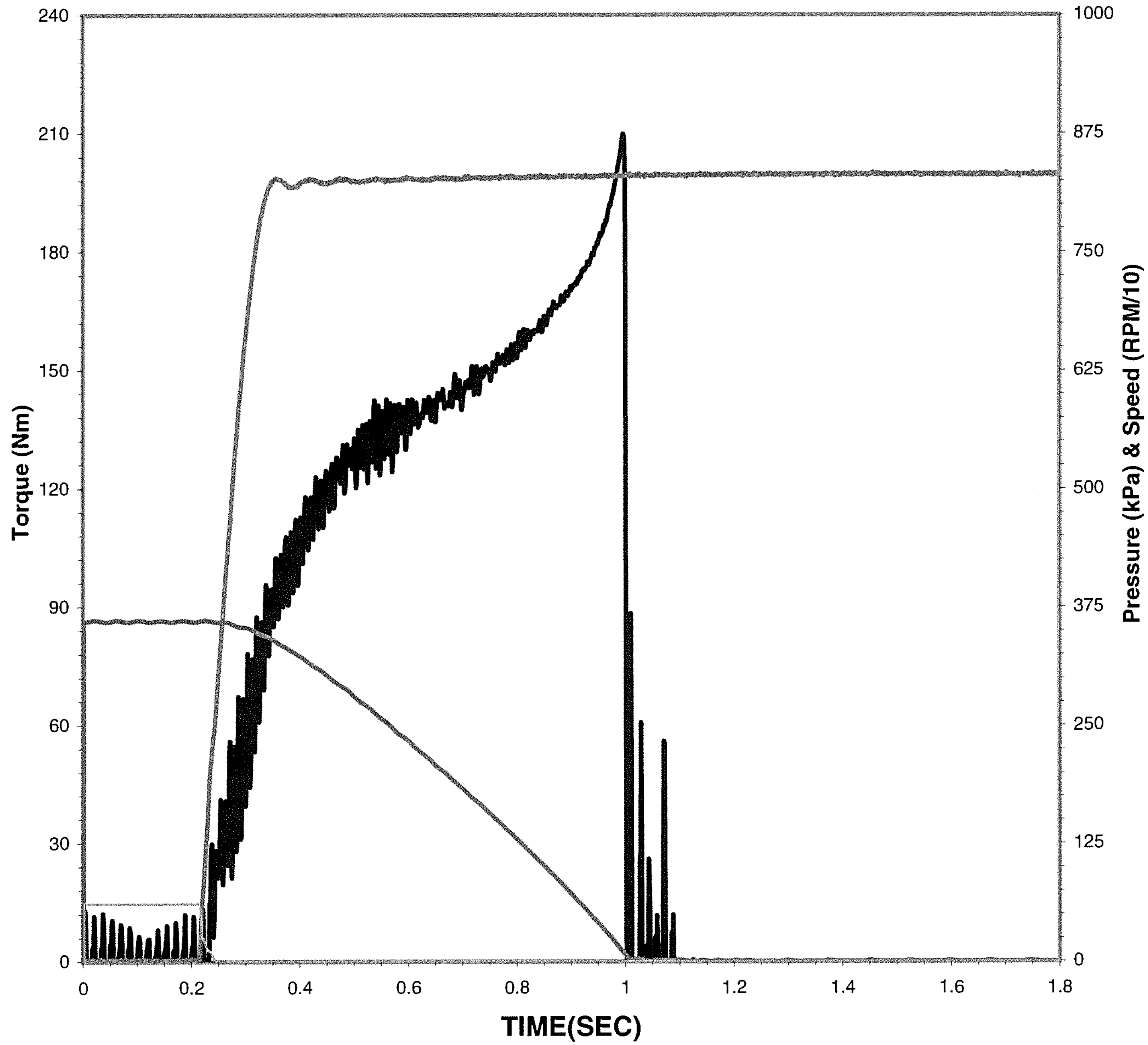
ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	19:25:24
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4001
Temperature:	107.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	826 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.787 Sec

Torque

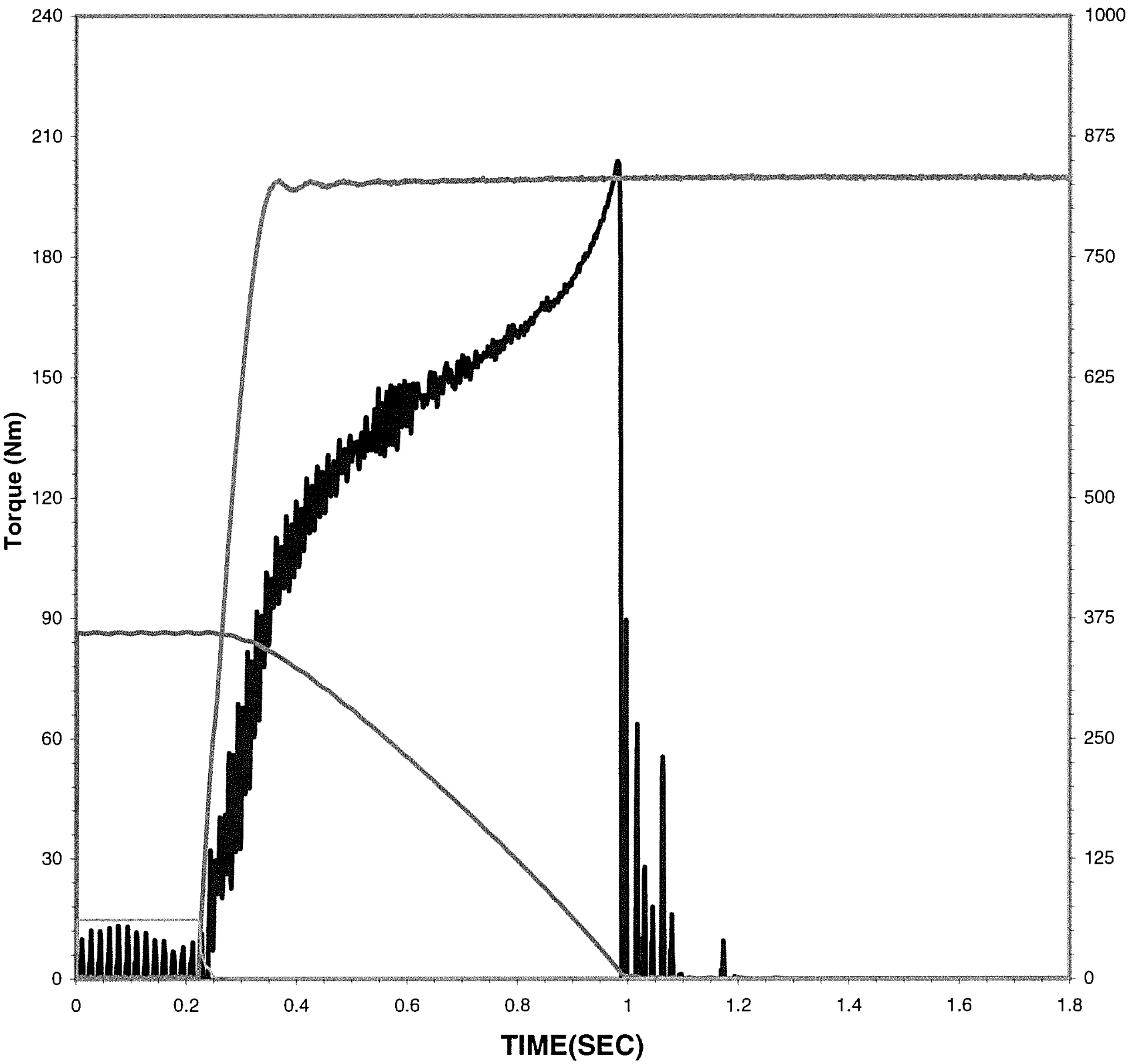
0.2 Sec Dyn:	113 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	209 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.144

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	21:29:54
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4499
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.766 Sec

Torque

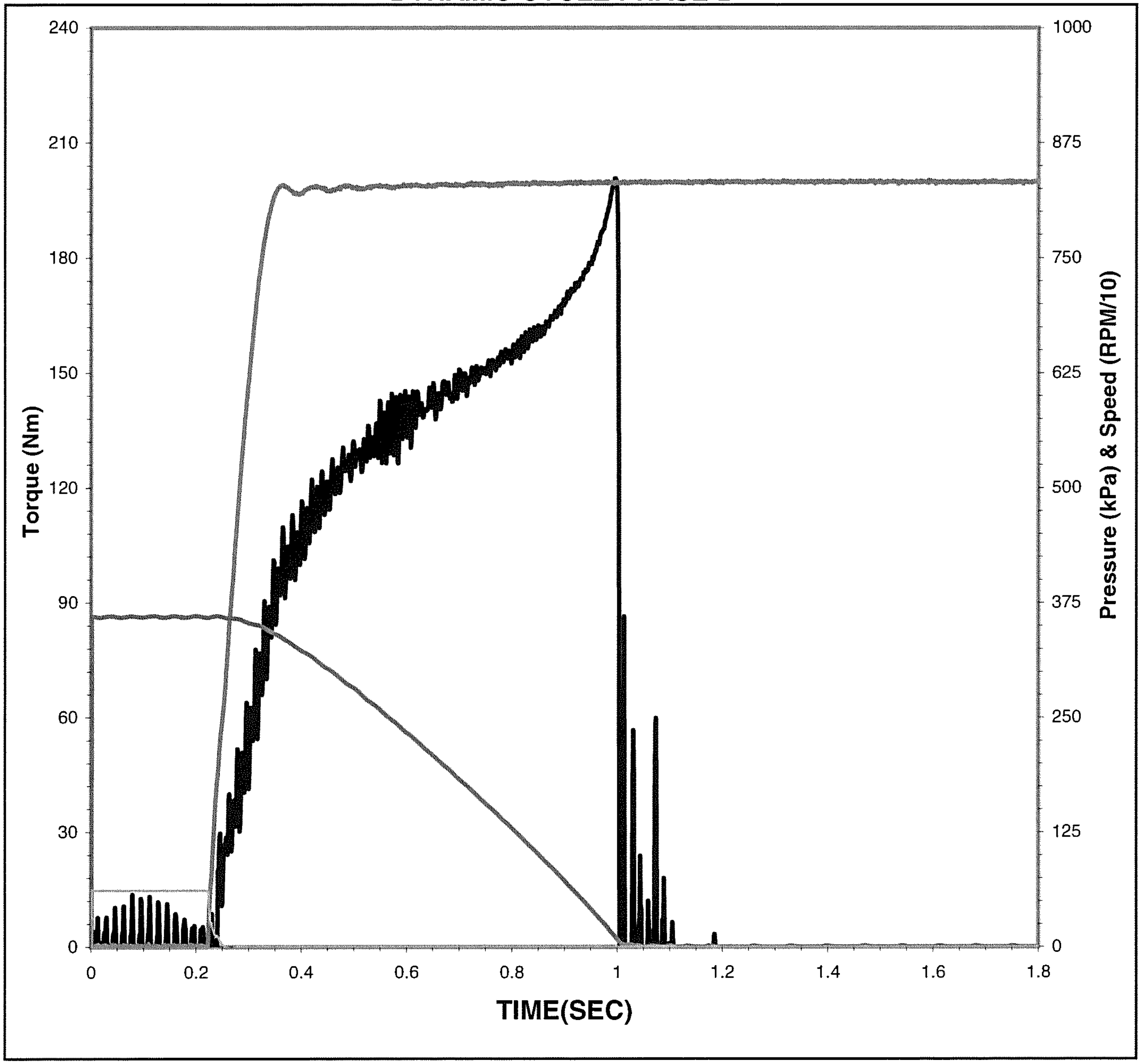
0.2 Sec Dyn:	119 N*m
Midpoint Dyn:	145 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.082
Midpoint Dyn:	0.100
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	21:30:09
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4500
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.782 Sec

Torque

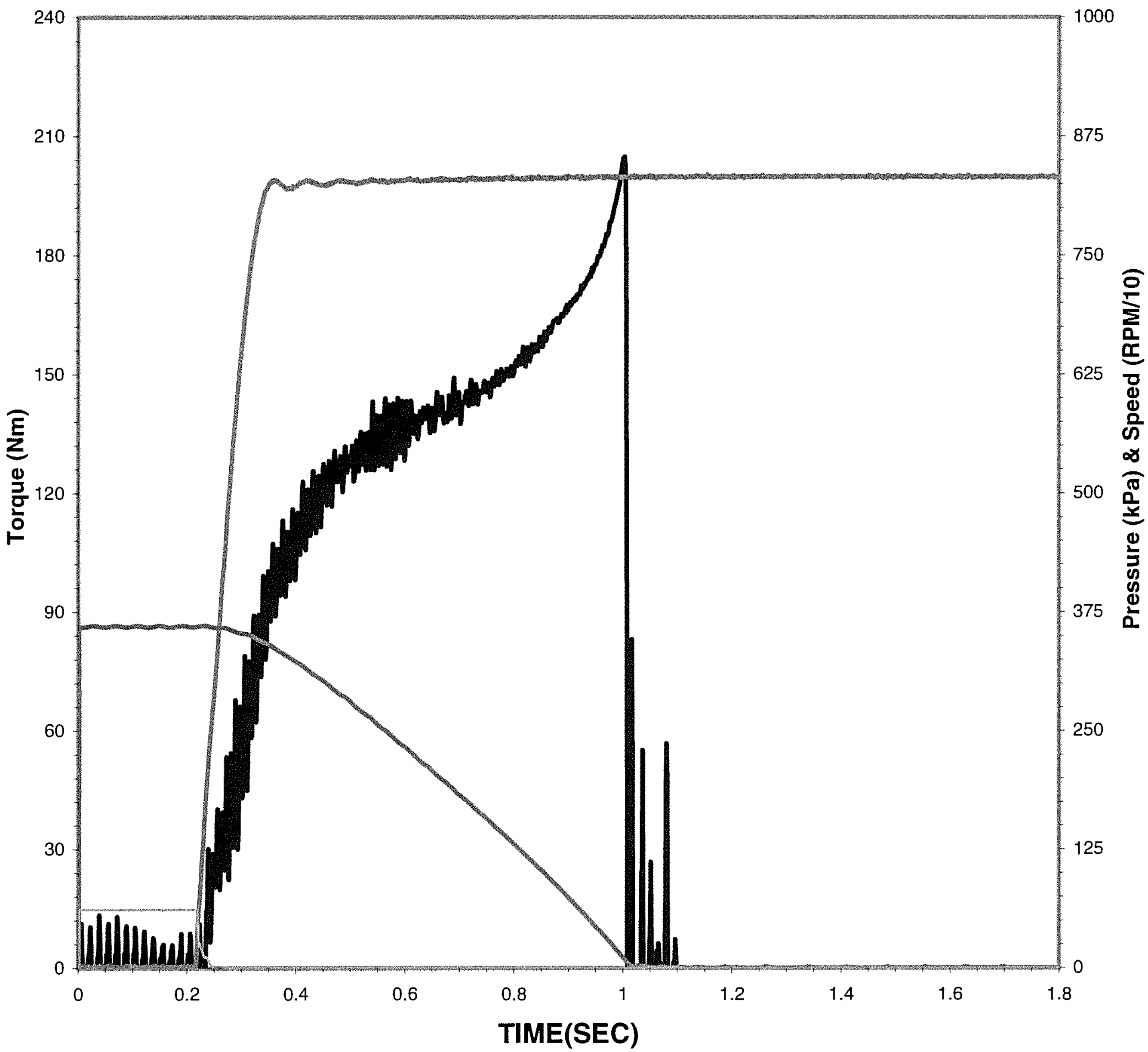
0.2 Sec Dyn:	116 N*m
Midpoint Dyn:	141 N*m
LwSpd Dynamic:	199 N*m

Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	21:30:36
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4501
Temperature:	106.9 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	828 kPa
	827 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.5 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.791 Sec

Torque

0.2 Sec Dyn:	116 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	204 N*m

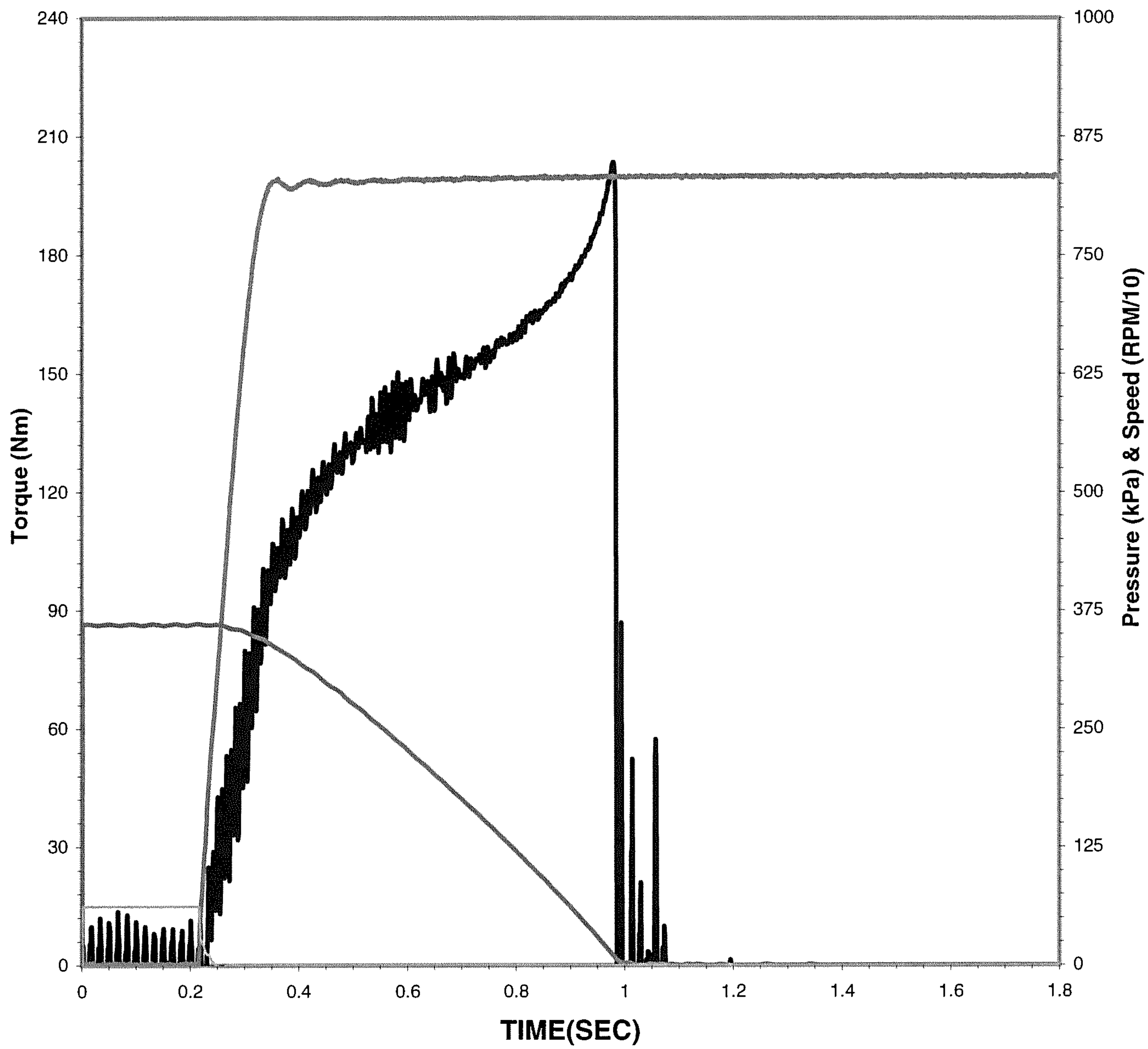
Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.141

A-37

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	23:35:06
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	4999
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.77 Sec

Torque

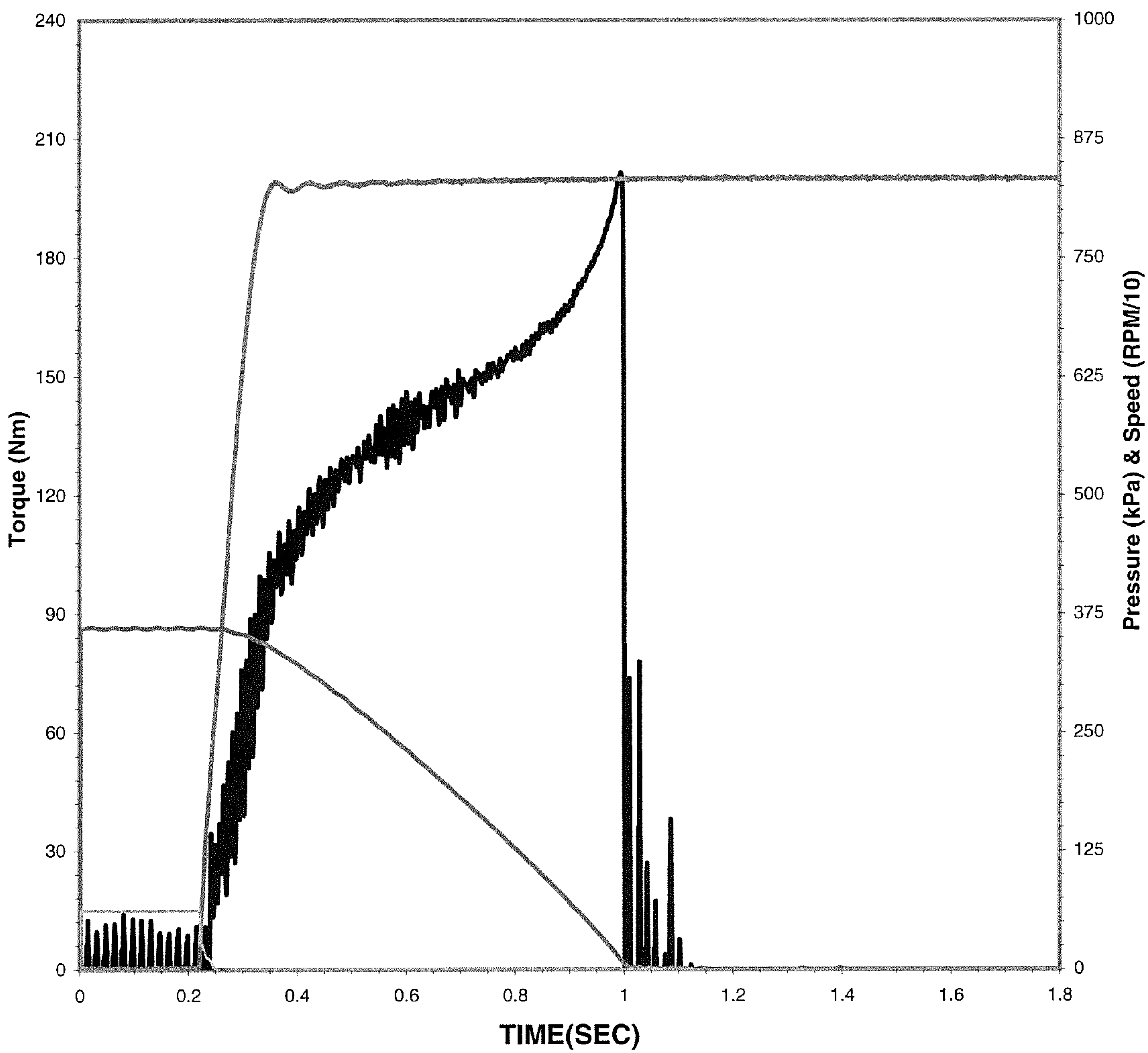
0.2 Sec Dyn:	118 N*m
Midpoint Dyn:	144 N*m
LwSpd Dynamic:	199 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/29/2014
Time of Test:	23:35:21
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	5000
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.781 Sec

Torque

0.2 Sec Dyn:	116 N*m
Midpoint Dyn:	140 N*m
LwSpd Dynamic:	197 N*m

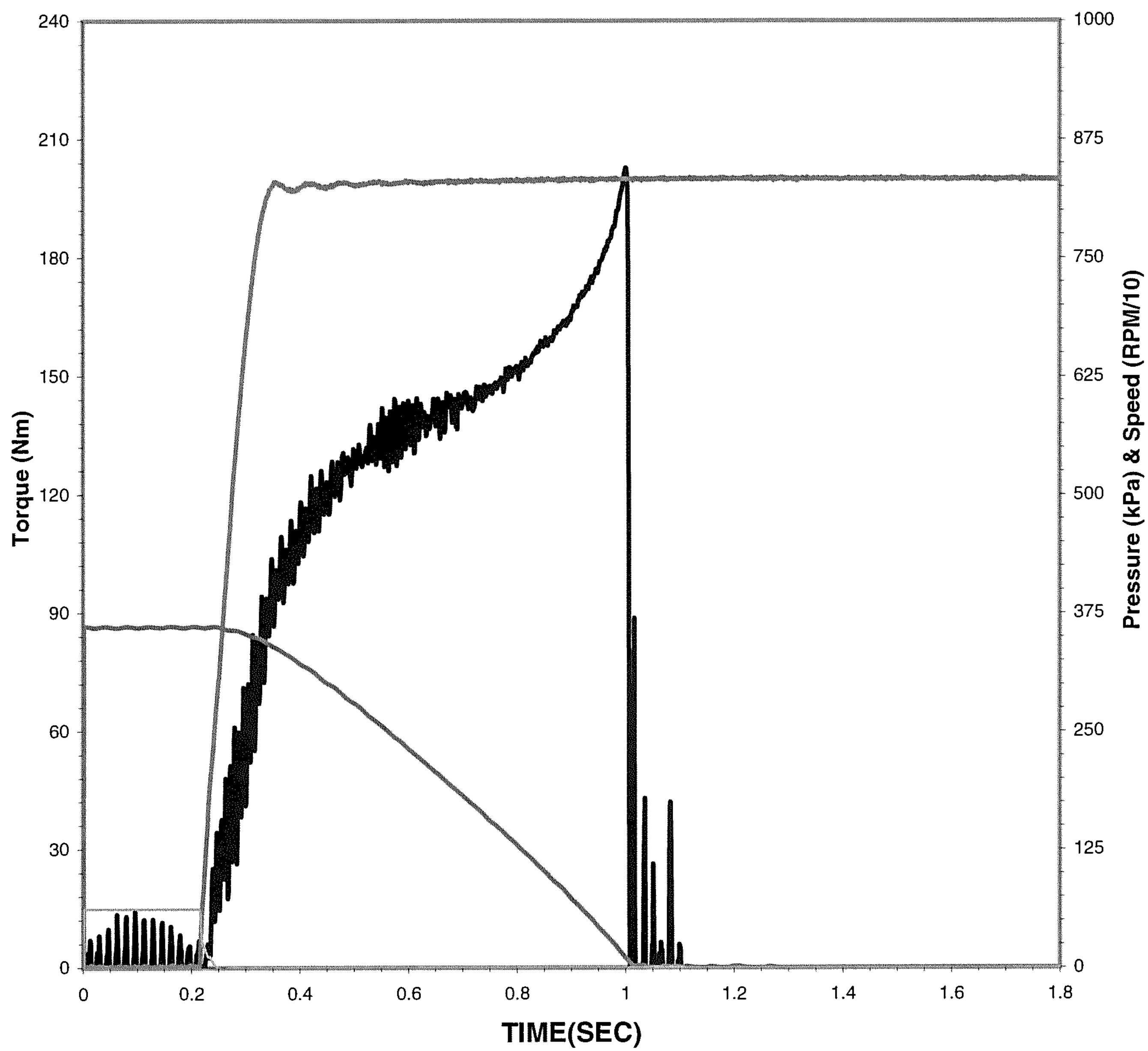
Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.136

A-39

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 1/29/2014

Time of Test: 23:35:47

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 5001

Temperature: 107.1 °C (112.7 ± 3.0 °C)

Apply Pressure: 829 kPa 827 ± 7 KPa)

Apply Rate: 0.14 Sec (0.15 ± 0.02 Sec)

Energy: 18.5 KJ (18.71 ± 0.40 KJ)

Engage Time: 0.792 Sec

Torque

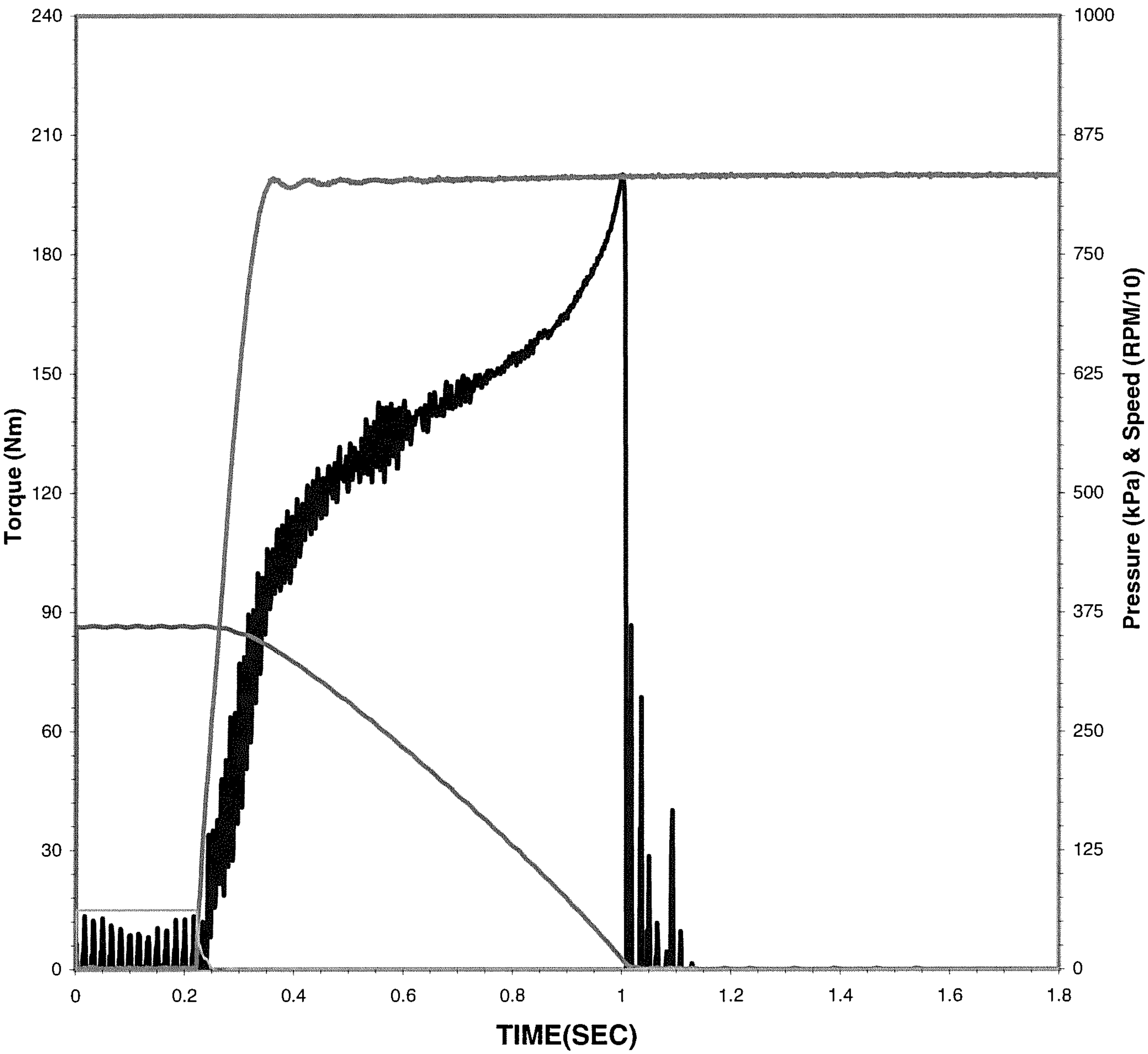
0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.136

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/30/2014
Time of Test:	1:40:02
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	5498
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.787 Sec

Torque

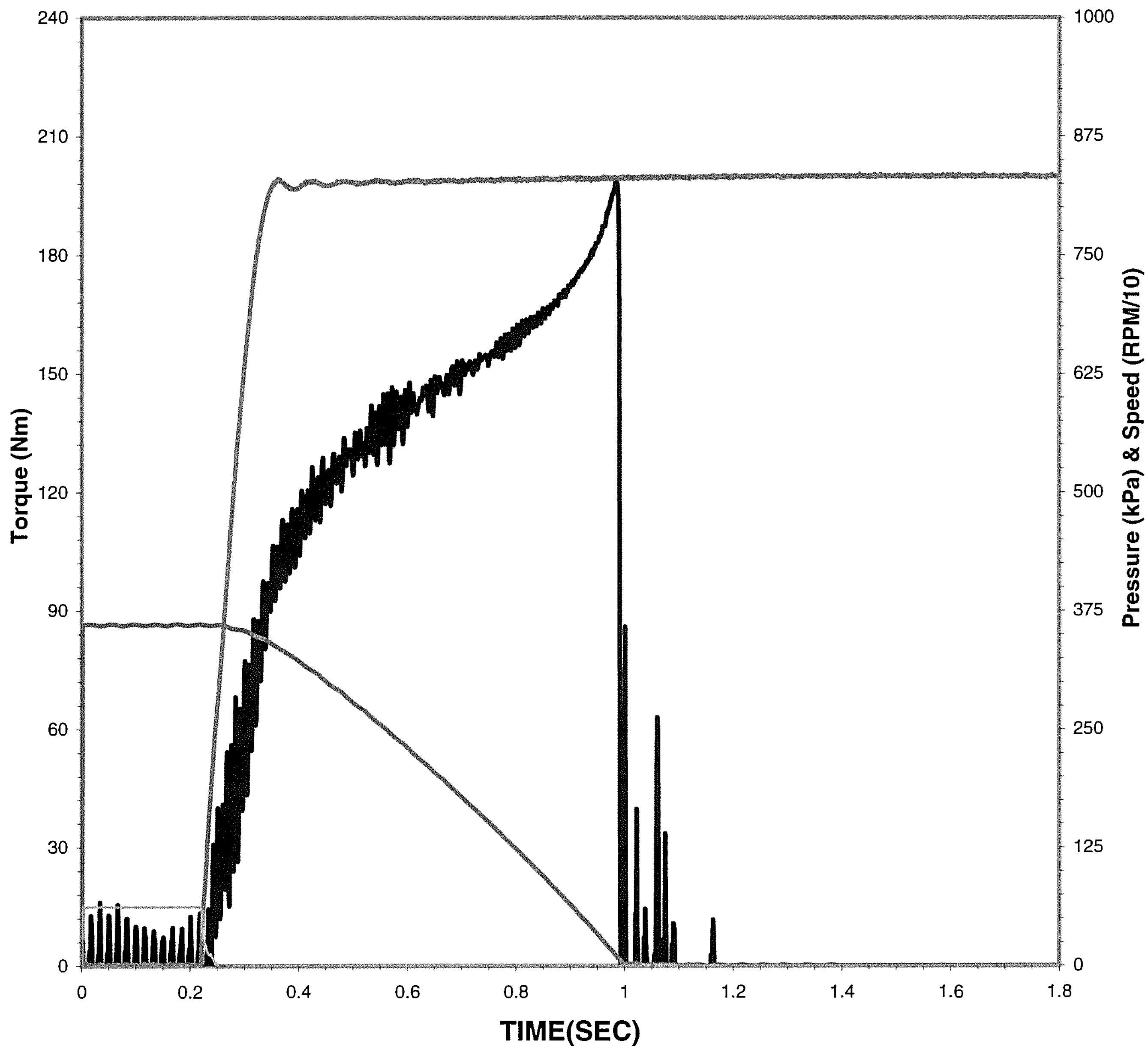
0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/30/2014
Time of Test:	1:40:18
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	5499
Temperature:	111.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.772 Sec

Torque

0.2 Sec Dyn:	119 N*m
Midpoint Dyn:	143 N*m
LwSpd Dynamic:	196 N*m

Coefficient of Friction

.2 Sec Dyn:	0.082
Midpoint Dyn:	0.099
LwSpd Dynamic:	0.136

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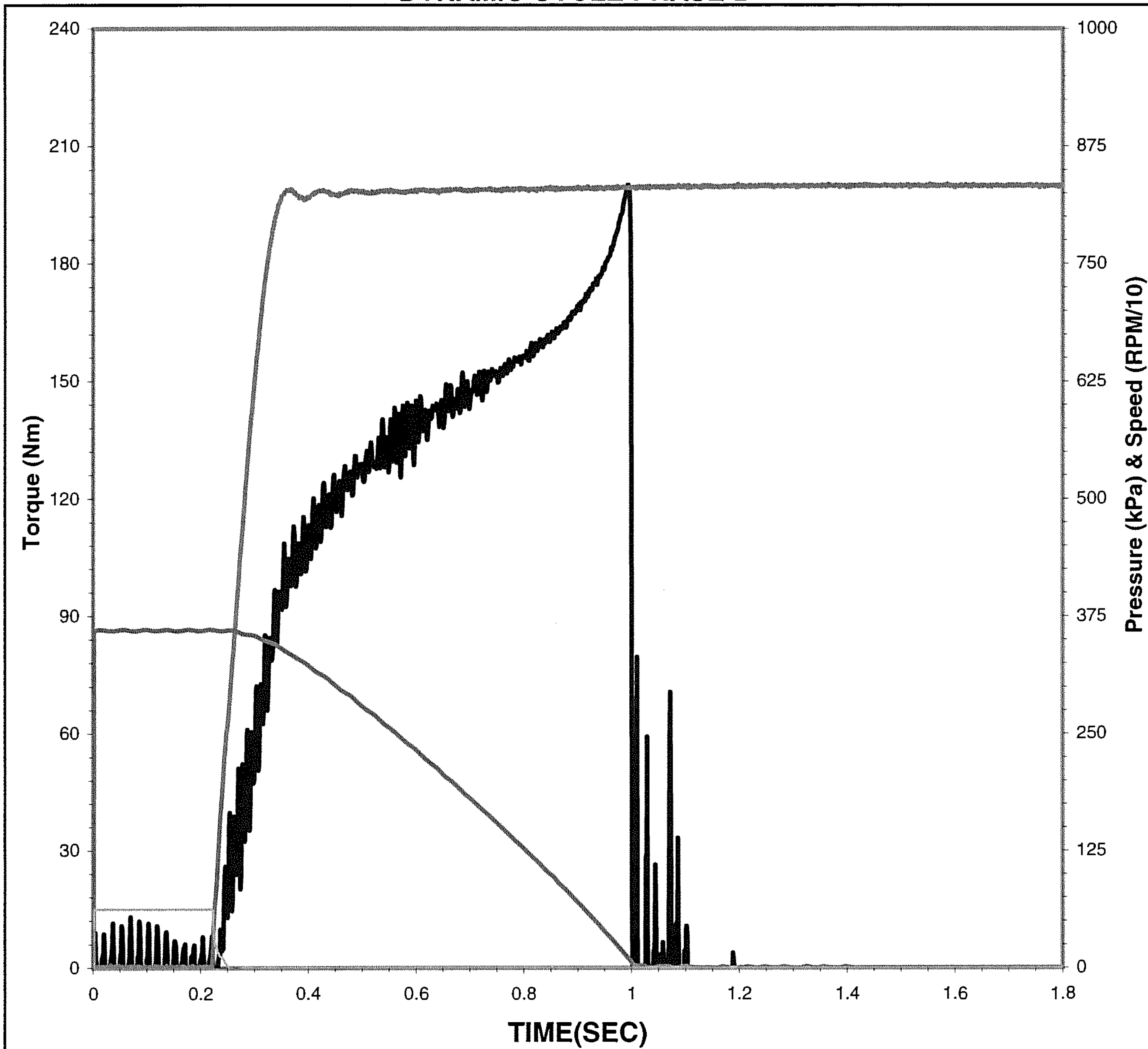
ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	1/30/2014
Time of Test:	1:40:33
Test Number:	C4-9-1449
Fluid Code:	LO292039
Cycle Number:	5500
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.78 Sec

Torque

0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	141 N*m
LwSpd Dynamic:	197 N*m

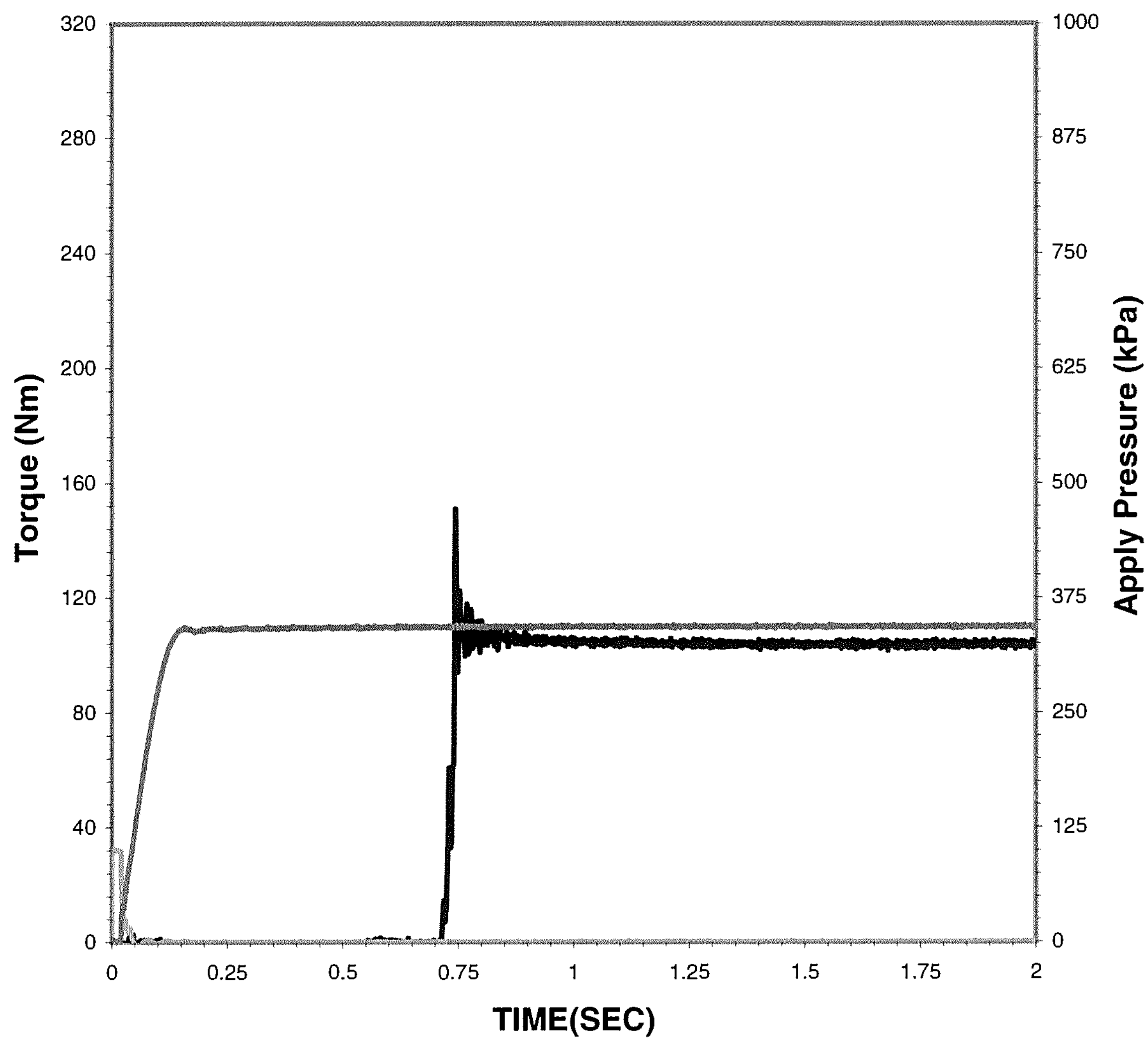
Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.136

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 2:37:05

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 10

PHASE A

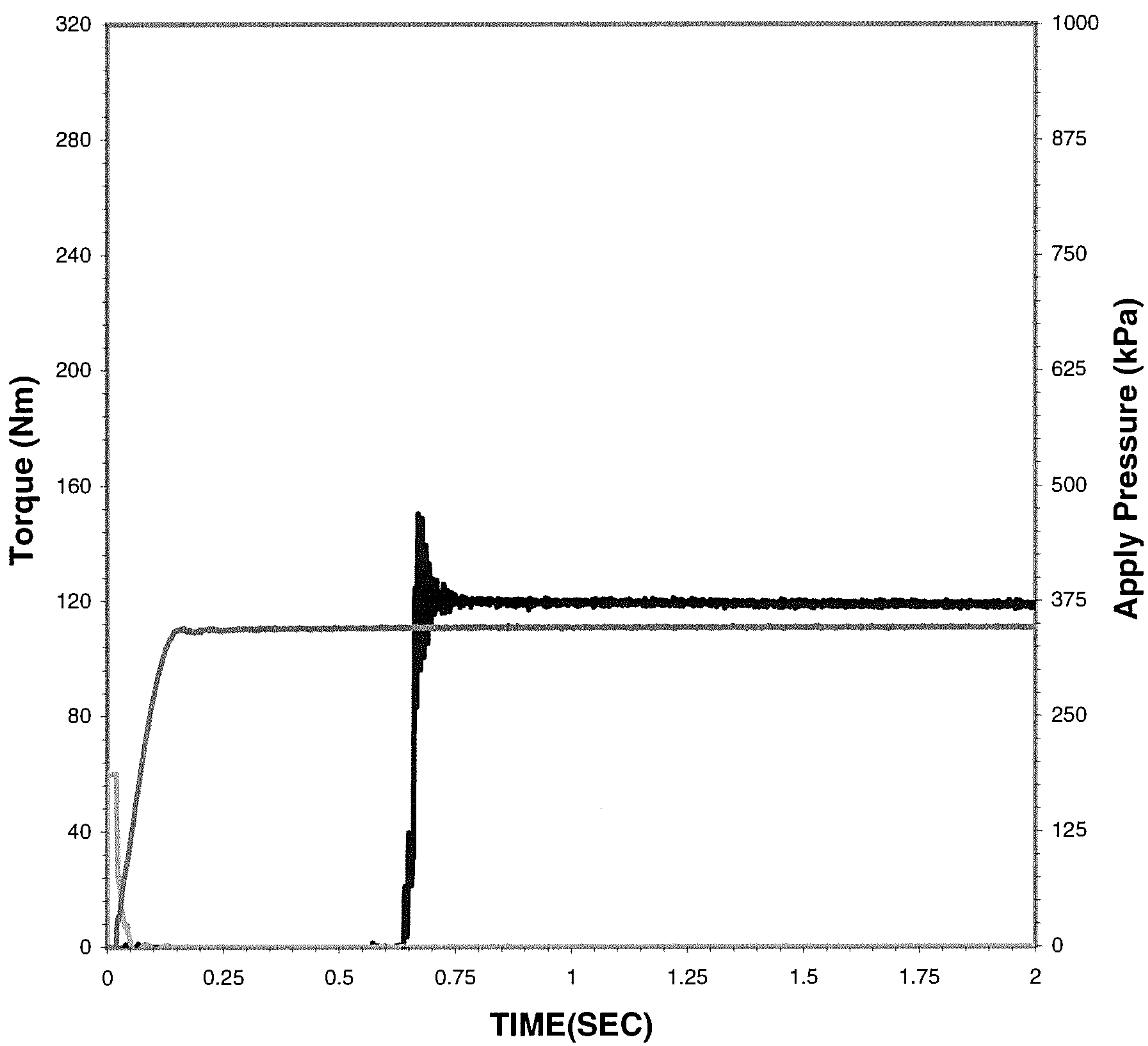
Apply Pressure:
At .25 Second: 341 kPa

Torque
Static Peak: 152 Nm
.25 Second: 105 Nm

Coefficient of Friction
Static Peak: 0.252
.25 Second: 0.174

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 4:39:47

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 500

PHASE A

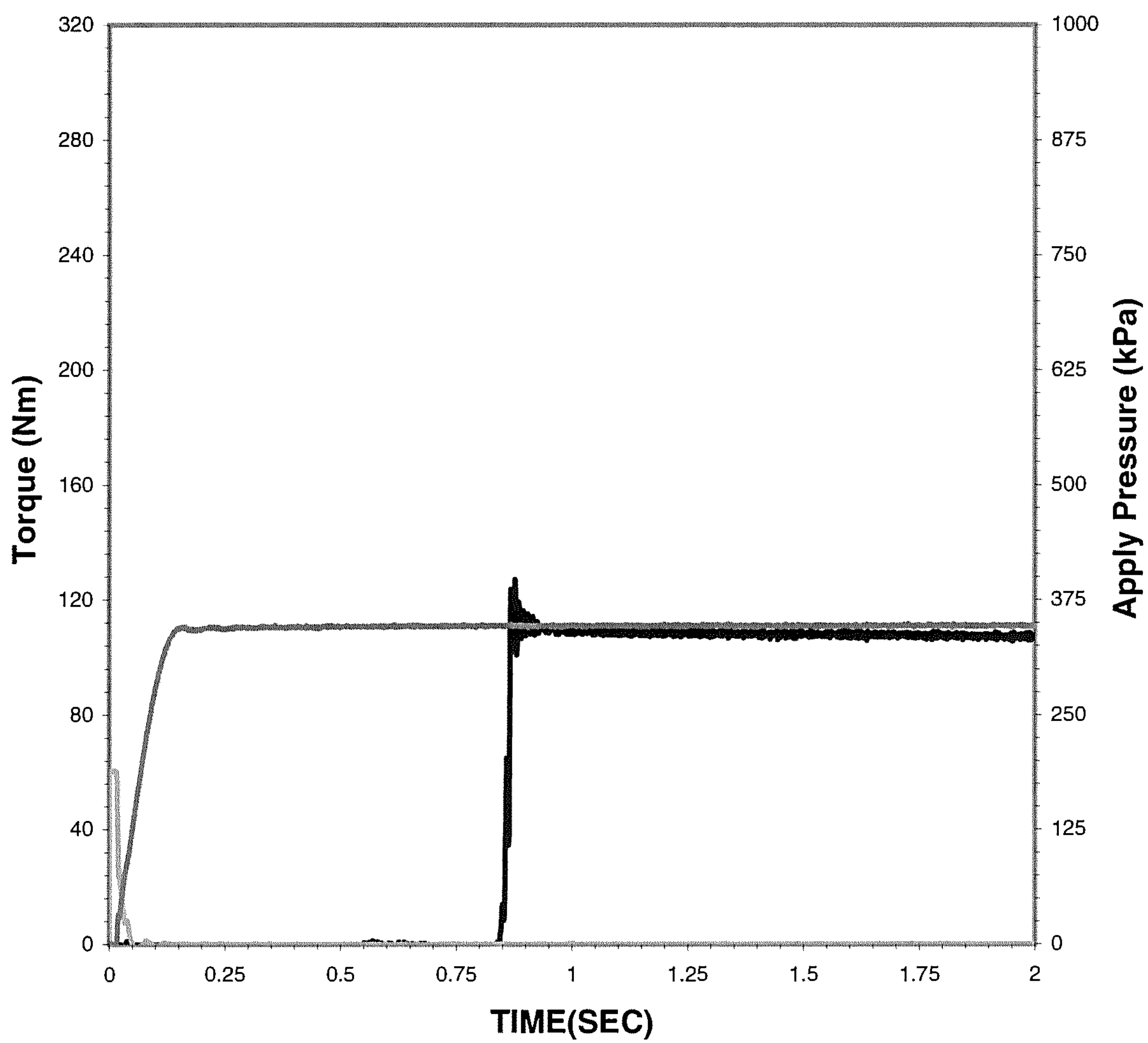
Apply Pressure:
At .25 Second: 346 kPa

Torque
Static Peak: 151 Nm
.25 Second: 122 Nm

Coefficient of Friction
Static Peak: 0.251
.25 Second: 0.202

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 6:44:59

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 1000

PHASE A

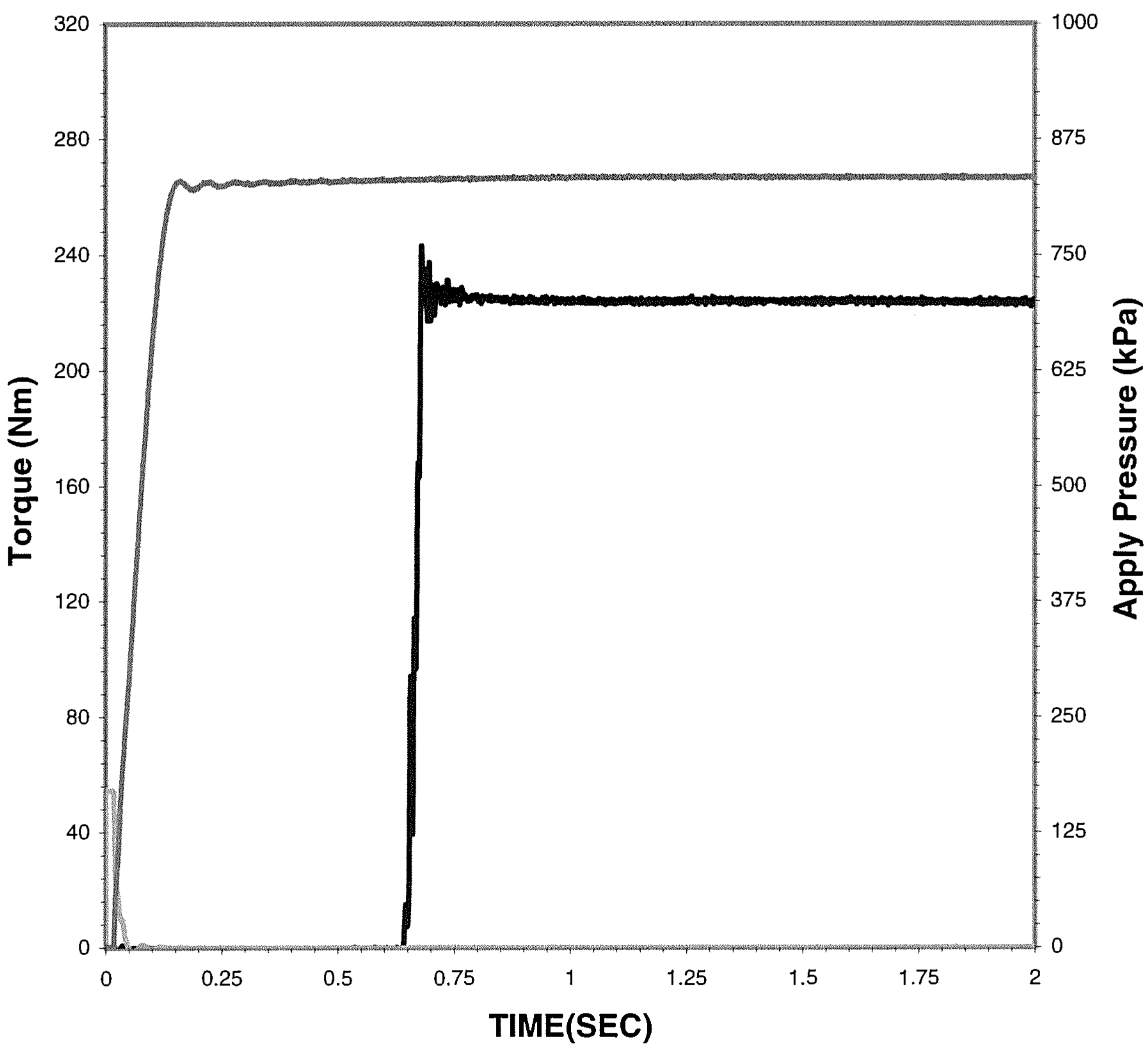
Apply Pressure:
At .25 Second: 346 kPa

Torque
Static Peak: 128 Nm
.25 Second: 110 Nm

Coefficient of Friction
Static Peak: 0.213
.25 Second: 0.182

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 8:59:10

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 1500

PHASE B

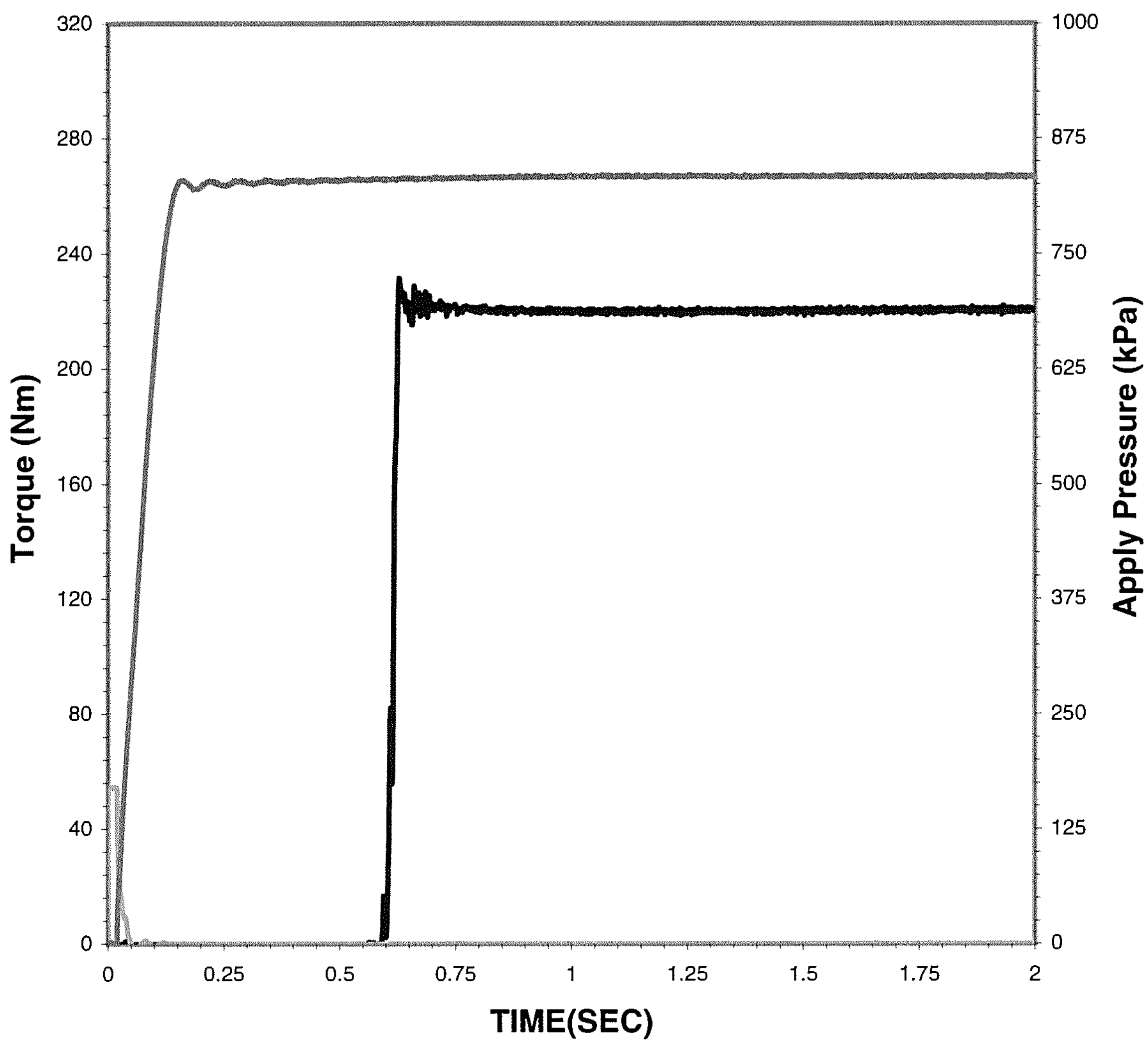
Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 244 Nm
.25 Second: 226 Nm

Coefficient of Friction
Static Peak: 0.169
.25 Second: 0.156

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 11:04:21

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 2000

PHASE B

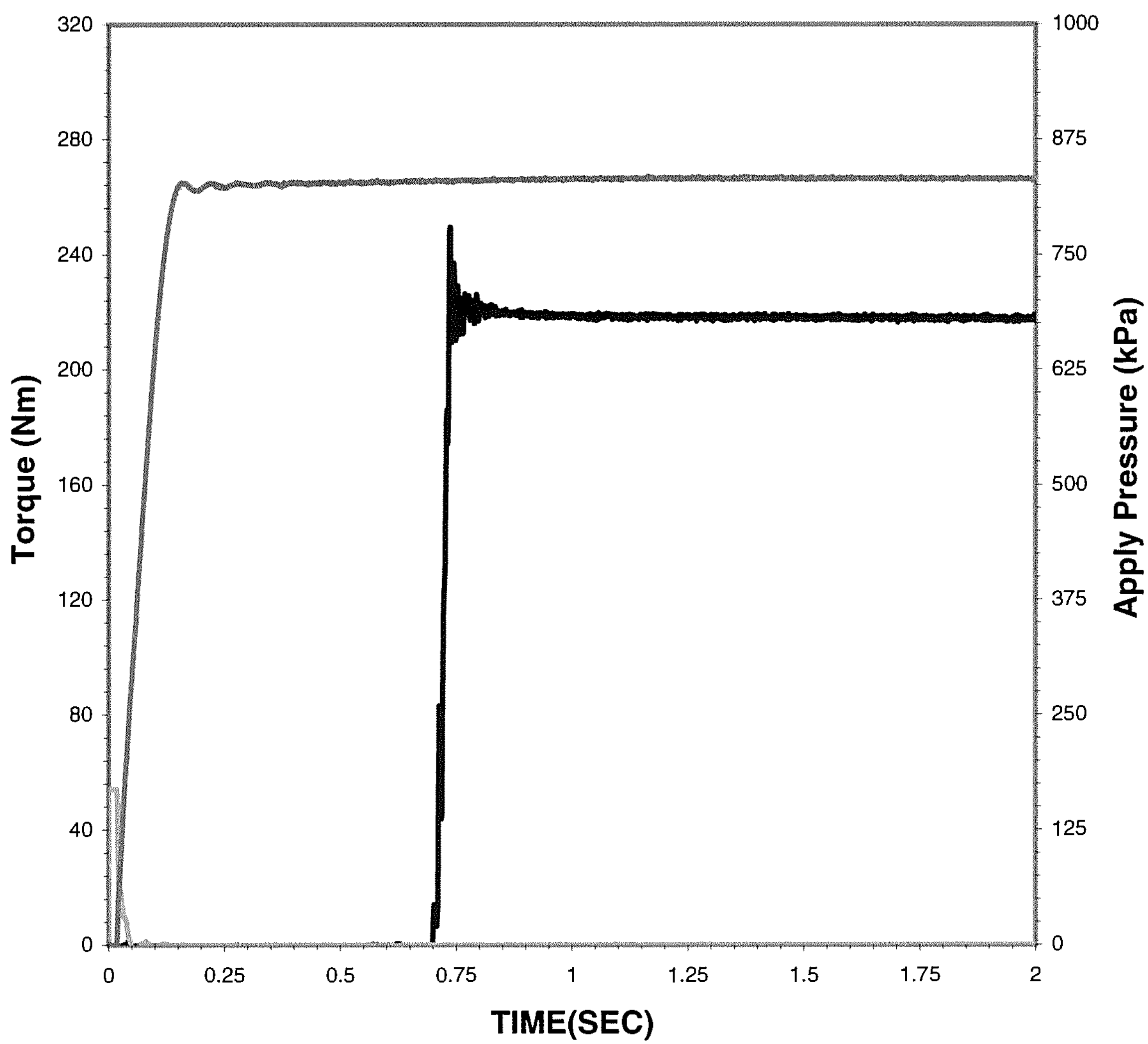
Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 232 Nm
.25 Second: 221 Nm

Coefficient of Friction
Static Peak: 0.161
.25 Second: 0.153

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 13:09:33

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 2500

PHASE B

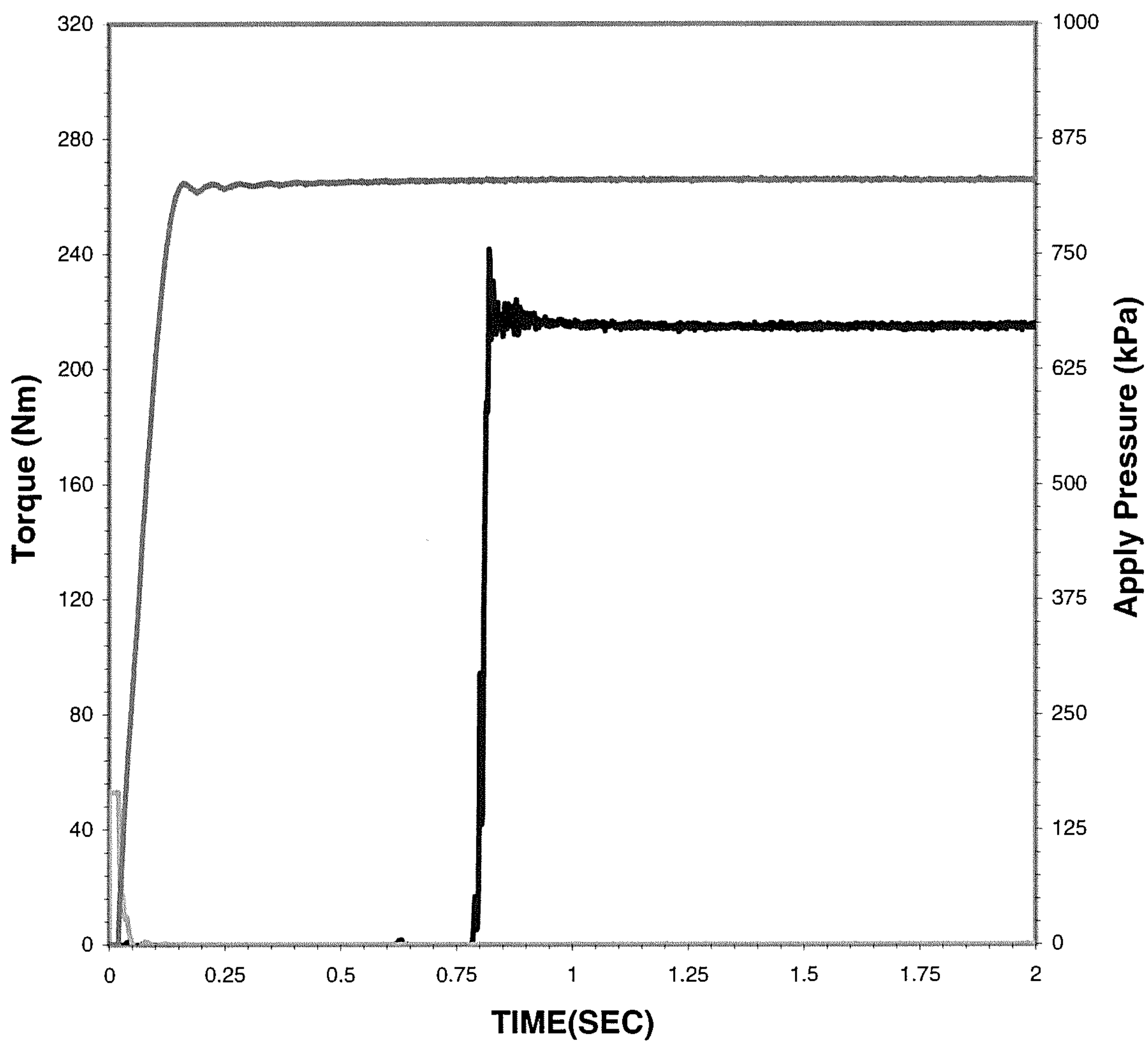
Apply Pressure:
At .25 Second: 826 kPa

Torque
Static Peak: 251 Nm
.25 Second: 220 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.152

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 15:14:45

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 3000

PHASE B

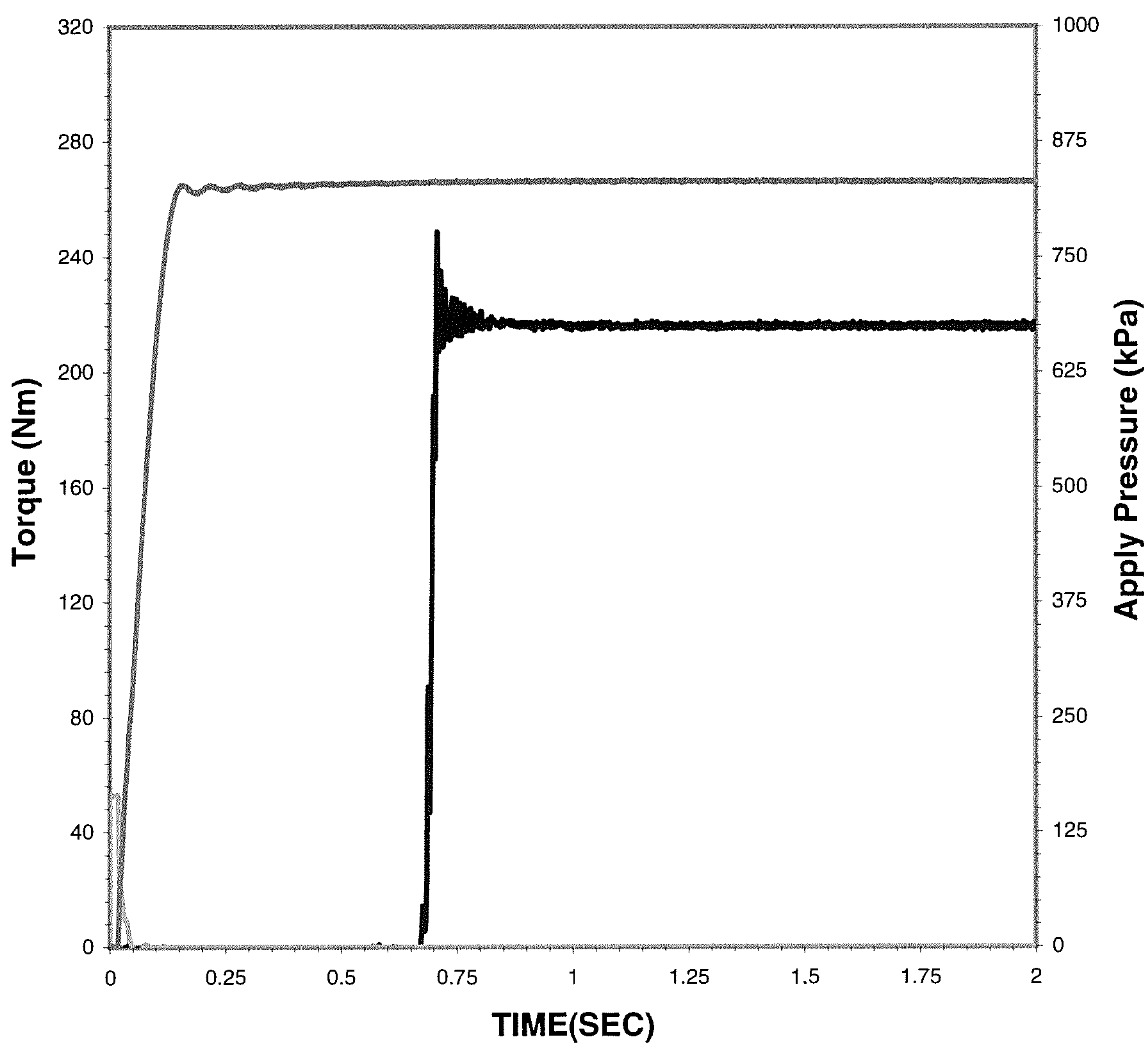
Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 243 Nm
.25 Second: 217 Nm

Coefficient of Friction
Static Peak: 0.168
.25 Second: 0.150

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 17:19:57

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 3500

PHASE B

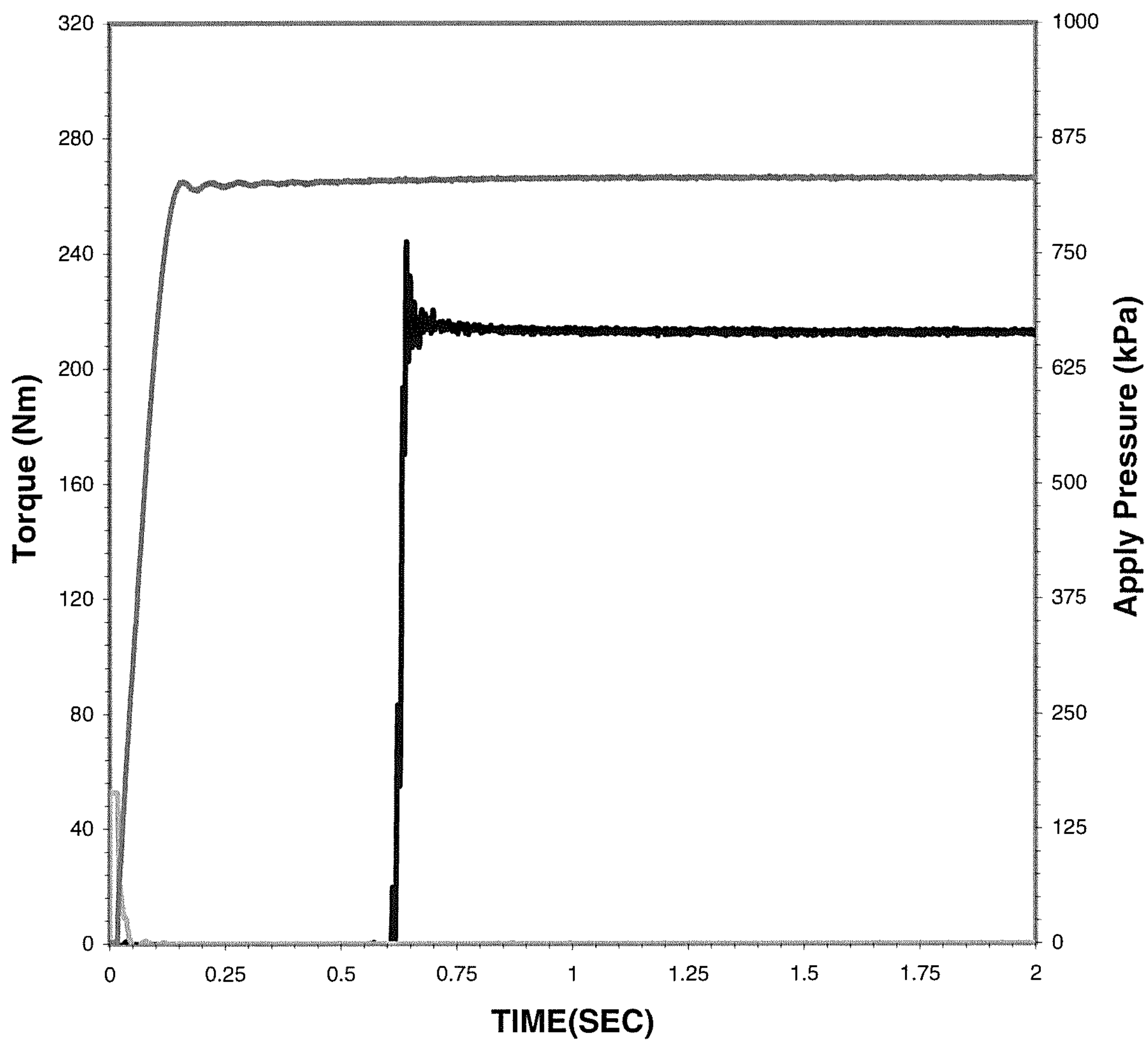
Apply Pressure:
At .25 Second: 826 kPa

Torque
Static Peak: 250 Nm
.25 Second: 218 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.151

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 19:25:09

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 4000

PHASE B

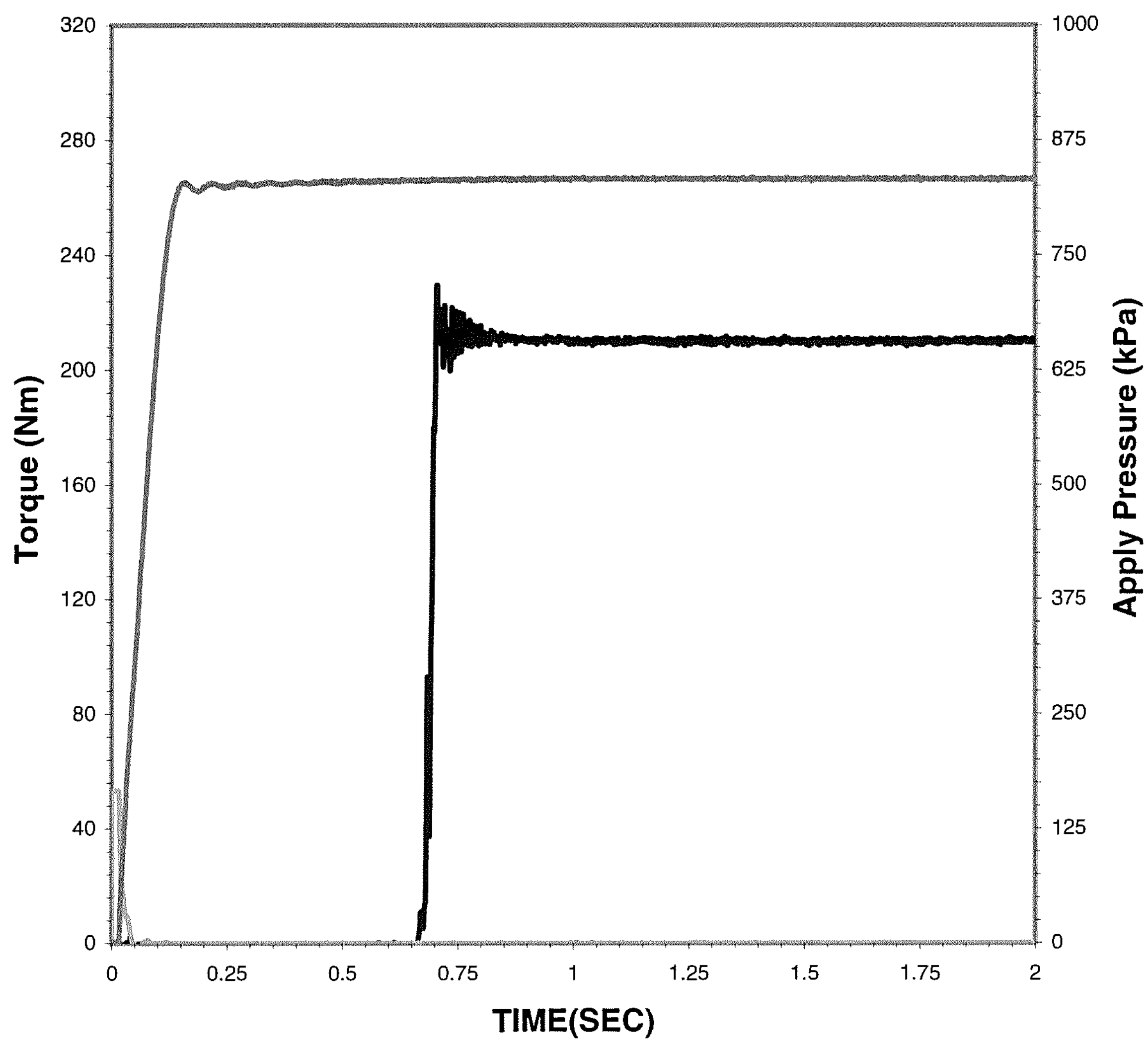
Apply Pressure:
At .25 Second: 826 kPa

Torque
Static Peak: 245 Nm
.25 Second: 215 Nm

Coefficient of Friction
Static Peak: 0.170
.25 Second: 0.148

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 21:30:20

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 4500

PHASE B

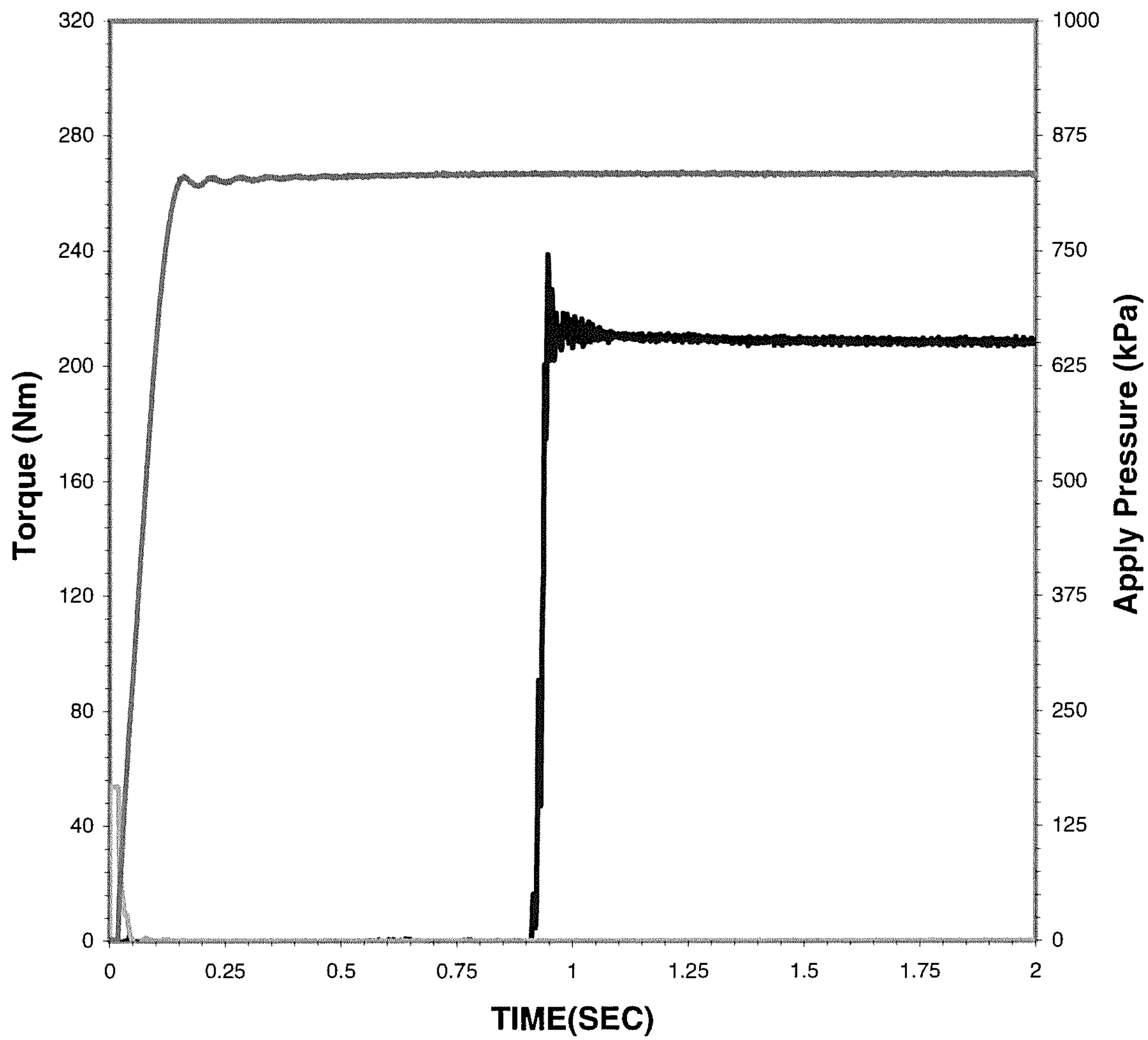
Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 231 Nm
.25 Second: 212 Nm

Coefficient of Friction
Static Peak: 0.159
.25 Second: 0.147

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 23:35:32

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 5000

PHASE B

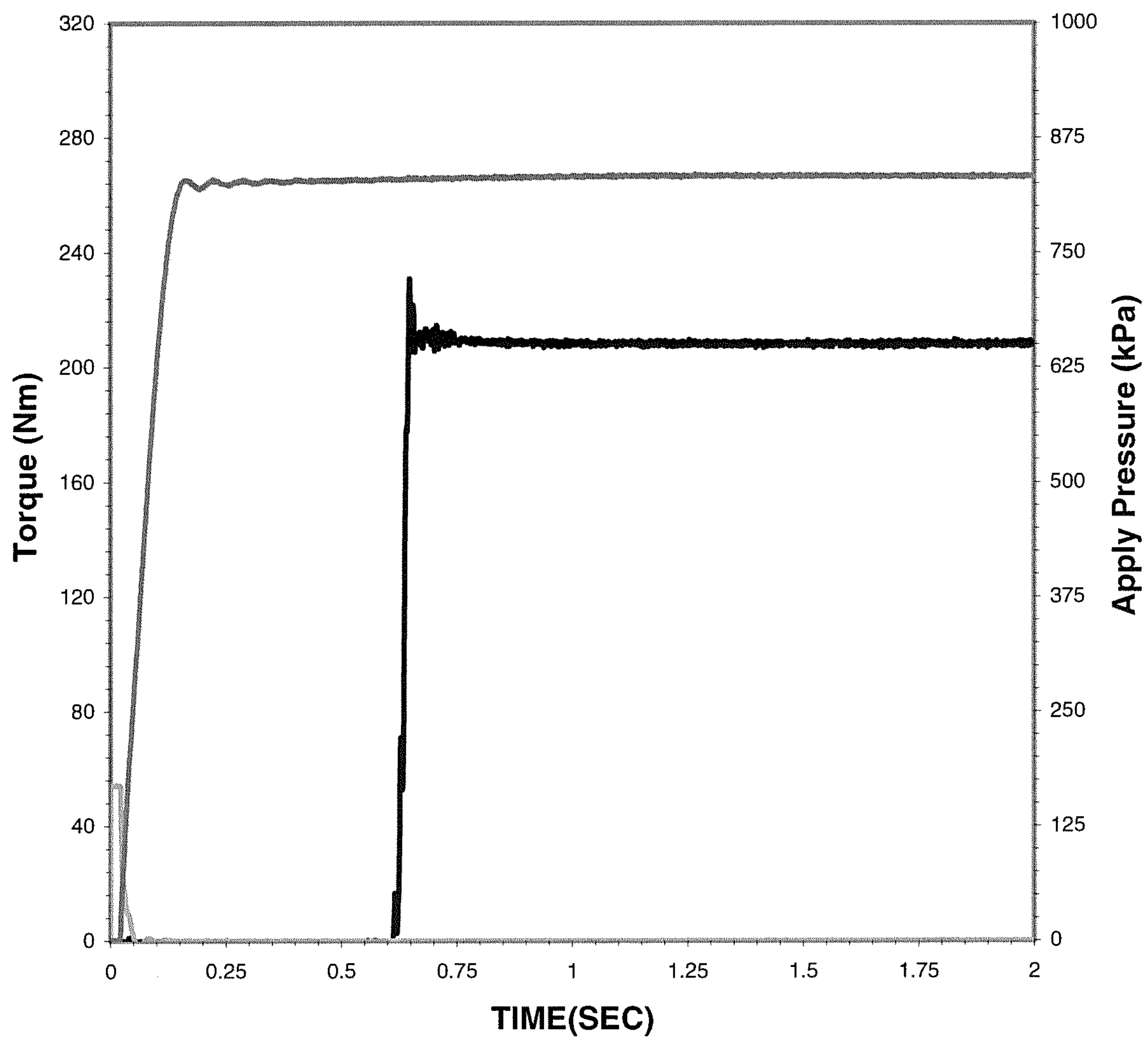
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 240 Nm
.25 Second: 212 Nm

Coefficient of Friction
Static Peak: 0.166
.25 Second: 0.146

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 1/30/2014

Time of Test: 1:40:44

Test Number: C4-9-1449

Fluid Code: LO292039

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 232 Nm
.25 Second: 211 Nm

Coefficient of Friction
Static Peak: 0.160
.25 Second: 0.146

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San Antonio, Texas

Fuels and Lubricants Research Division

This page has been AMENDED.
Initial: [illegible]
Date: 3/24/14

Report on

ALLISON TRANSMISSION FLUID
TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO292039

Test Number:
C2-7-1615

January 29, 2014

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

This page has been AMENDED.
Initial: JWO
Date: 5/5/14

IX. Paper Clutch Friction Test

Test Laboratory:	SWRI	Lab Fluid Code:	LO-292039
Test Number:	C2-7-1615	Sponsor Fluid Code:	LO292039
Friction Plate Batch:	LOT 6	Completion Date:	01/29/14
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0001
Clutch Plate	0.1170	0.0988

	Before	After
Pack Clearance	1.0414	1.2446

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1581	06/04/12	TRANSYND RD 07-27-11
C2-0-1592	01/04/13	RDL-2746 08-12
C2-0-1608	10/10/13	RDL-2746 08-12

	New	EOT
Viscosity at 40°C, cSt	45.28	39.12
Viscosity at 100°C, cSt	8.53	7.70
Iron Content, ppm	1	183

D5185	New Fluid (ppm)
Ba	<1
B	16
Ca	973
Mg	1305
P	1142
Si	6
Na	10
Zn	1244

Name: Matthew Jackson

Title: Manager

Signature:

Date: 2/6/14

ALLISON C- 4 PAPER FRICTION TEST
(Torque in N*m)

Sponsor Fluid Code:	**LO292039**	Test Number:	**C2-7-1615**
Lab Fluid Code:	**LO-292039**	Fric. Plate Batch:	**LOT 6**
Completion Date:	**01/29/2014**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.50	197	350	153	380	362
500	0.47	209	356	147	380	367
1000	0.45	223	344	121	364	358
2500	0.43	238	335	97	344	338
5000	0.42	246	326	80	337	328
7500	0.43	239	324	85	336	325
10000	0.43	239	312	73	333	321

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.50	0.096	0.170	0.074	0.185	0.176
500	0.47	0.102	0.173	0.071	0.185	0.179
1000	0.45	0.109	0.168	0.059	0.177	0.174
2500	0.43	0.116	0.163	0.047	0.168	0.165
5000	0.42	0.120	0.159	0.039	0.164	0.160
7500	0.43	0.116	0.158	0.042	0.164	0.158
10000	0.43	0.116	0.152	0.036	0.162	0.156

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.500	0.430	-14.00	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.096	0.116	20.83	P
Static Friction Coeff.	N/A	N/A	0.170	0.152	-10.59	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.185	0.162	-12.43	
0.25 Second Low Speed Coeff.	N/A	N/A	0.176	0.156	-11.36	

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ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO292039 **Test Number : C2-7-1615** **Completion Date : 1/29/2014**
Lab Fluid Code : LO-292039 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 6**

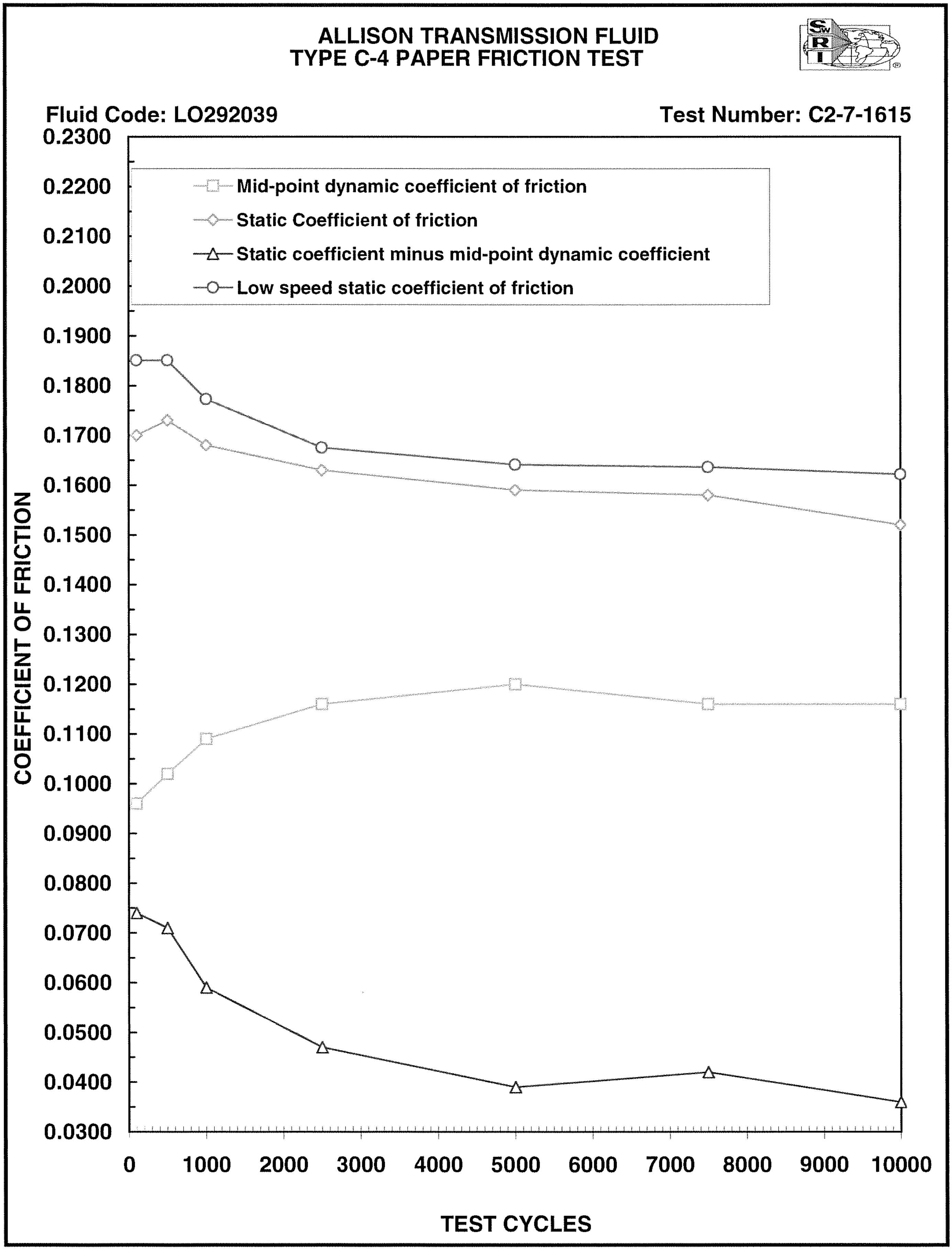
Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0630	1.9500	2.0510	1.9580	0.1130		0.0930
	120	2.0620	1.9570	2.0510	1.9680	0.1050		0.0830
	240	2.0640	1.9640	2.0550	1.9780	0.1000		0.0770
	Average					0.1060	0.0952	0.0843
5	Top	2.0620	1.9570	2.0500	1.9670	0.1050		0.0830
	120	2.0600	1.9430	2.0450	1.9510	0.1170		0.0940
	240	2.0610	1.9480	2.0520	1.9500	0.1130		0.1020
	Average					0.1117	0.1024	0.0930
STEELS SEPARATORS								
1	Top	1.7520	1.7520	1.7520	1.7520	0.0000		0.0000
	120	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	240	1.7520	1.7520	1.7530	1.7520	0.0000		0.0010
	Average					0.0000	0.0002	0.0003
3	Top	1.7480	1.7480	1.7480	1.7480	0.0000		0.0000
	120	1.7480	1.7480	1.7490	1.7490	0.0000		0.0000
	240	1.7480	1.7480	1.7490	1.7490	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
4	Top	1.7490	1.7490	1.7490	1.7490	0.0000		0.0000
	120	1.7490	1.7490	1.7490	1.7490	0.0000		0.0000
	240	1.7480	1.7480	1.7470	1.7470	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7670	1.7660	1.7690	1.7690	0.0010		0.0000
	120	1.7670	1.7670	1.7670	1.7670	0.0000		0.0000
	240	1.7700	1.7700	1.7700	1.7700	0.0000		0.0000
	Average					0.0003	0.0002	0.0000

PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION WITH LIGHT DISCOLORATION ON INNER STEEL
(Anything Unusual) PLATES. MICROMETER #0221190

Test Date and Operator's Name: 1/29/2014 MARK HOLMES

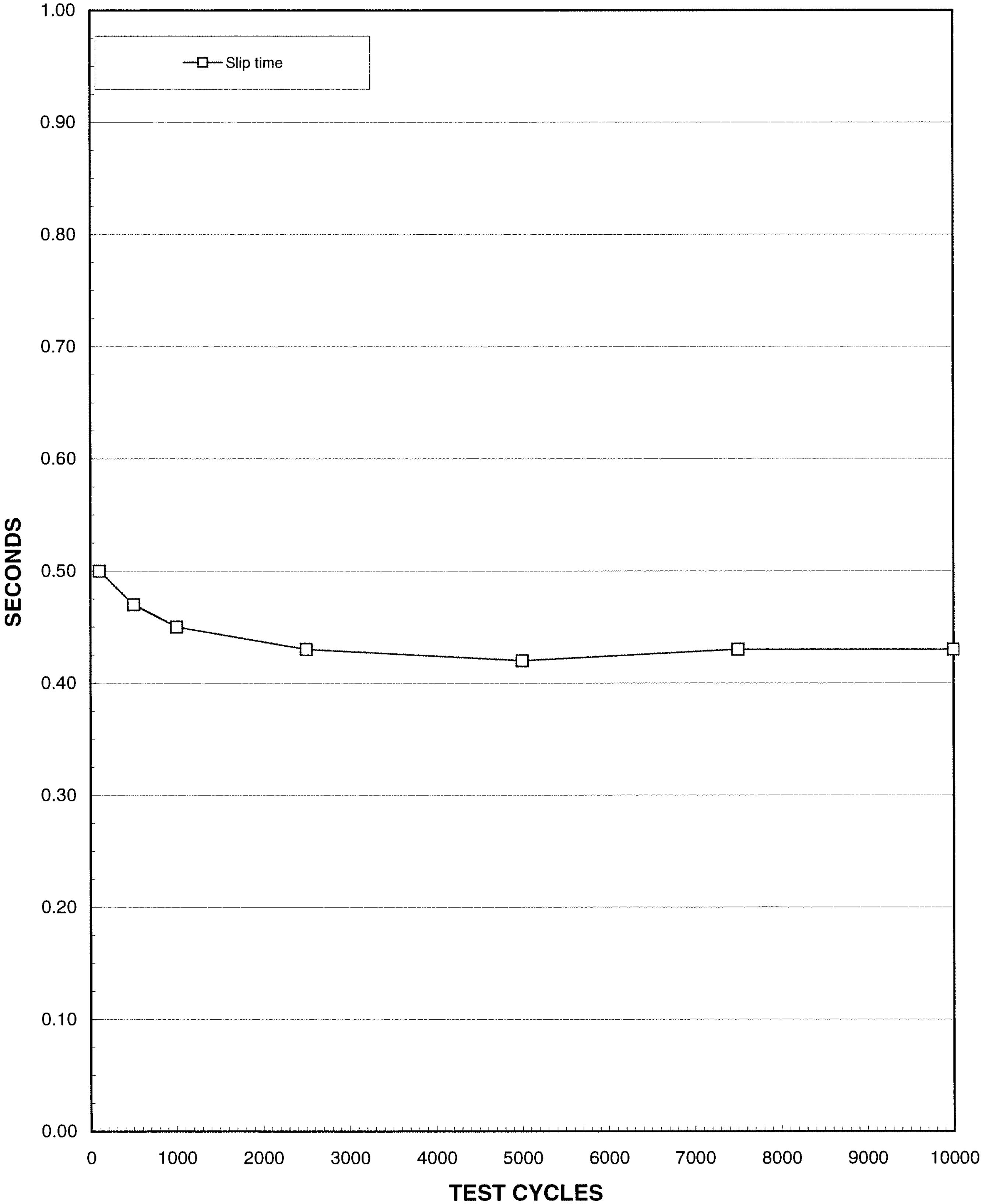
Reviewed By (Signature and Date) 2/6/14

Pack ID#: 5107


ALLISON TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO292039
Test Number: C2-7-1615
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
TEST CYCLES
0.2300
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

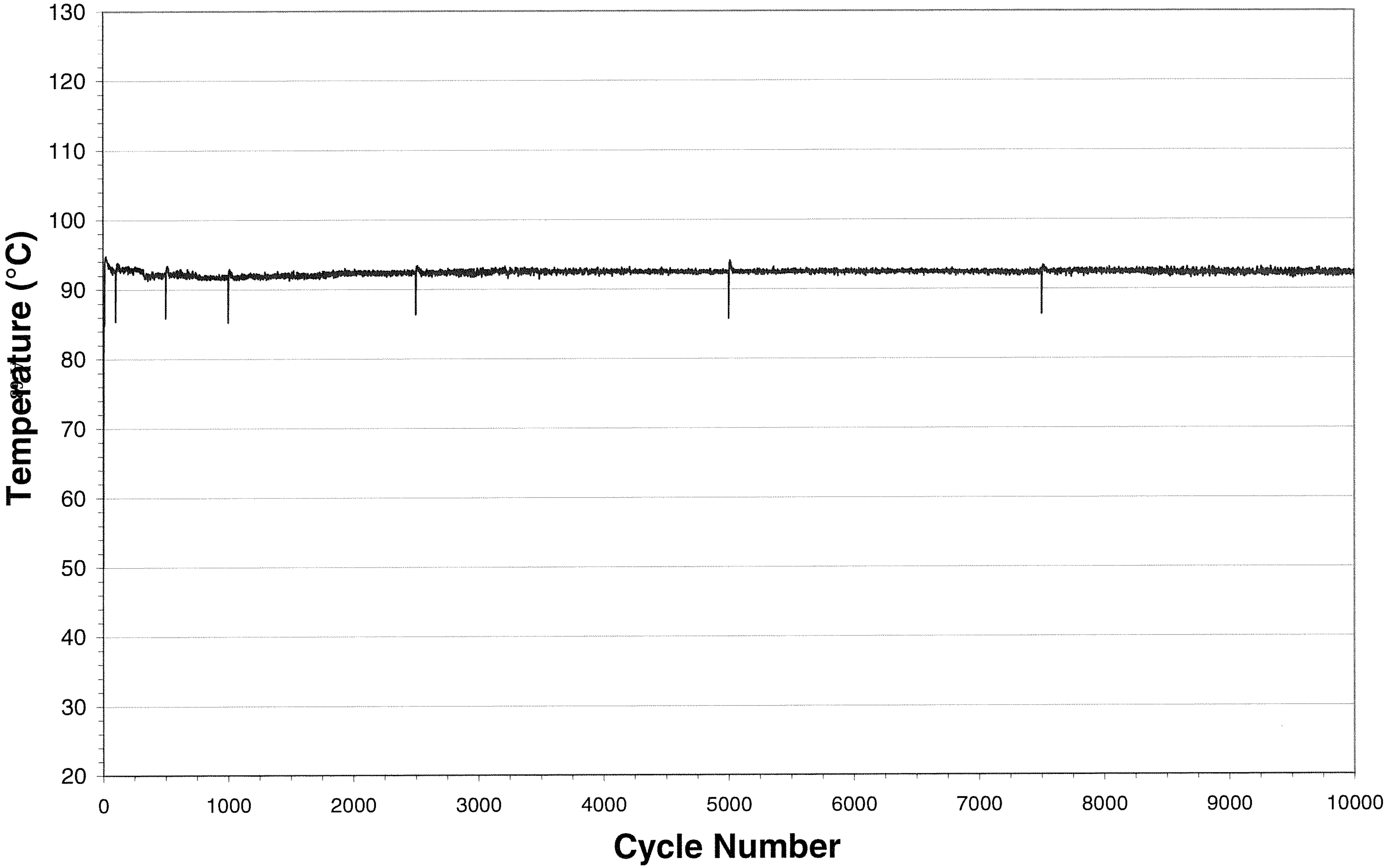
ALLISON TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO292039 **Test Number: C2-7-1615**



C2-7-1615   LO292039

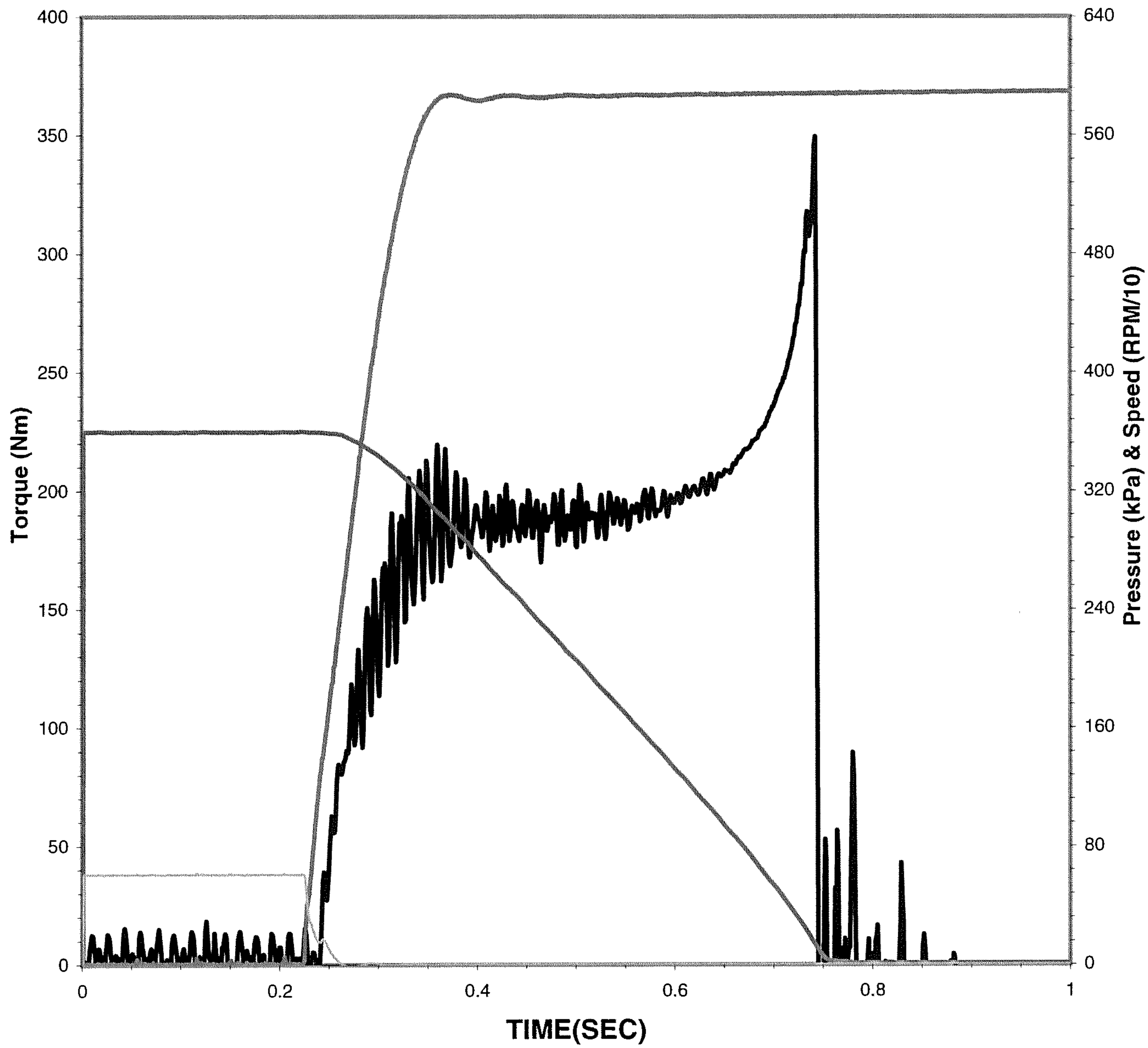
Temp: Max=94.8°C Min=50.2°C Avg=92.4°C



DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	16:12:56
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	10
Temperature:	89.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.519 Sec

Torque

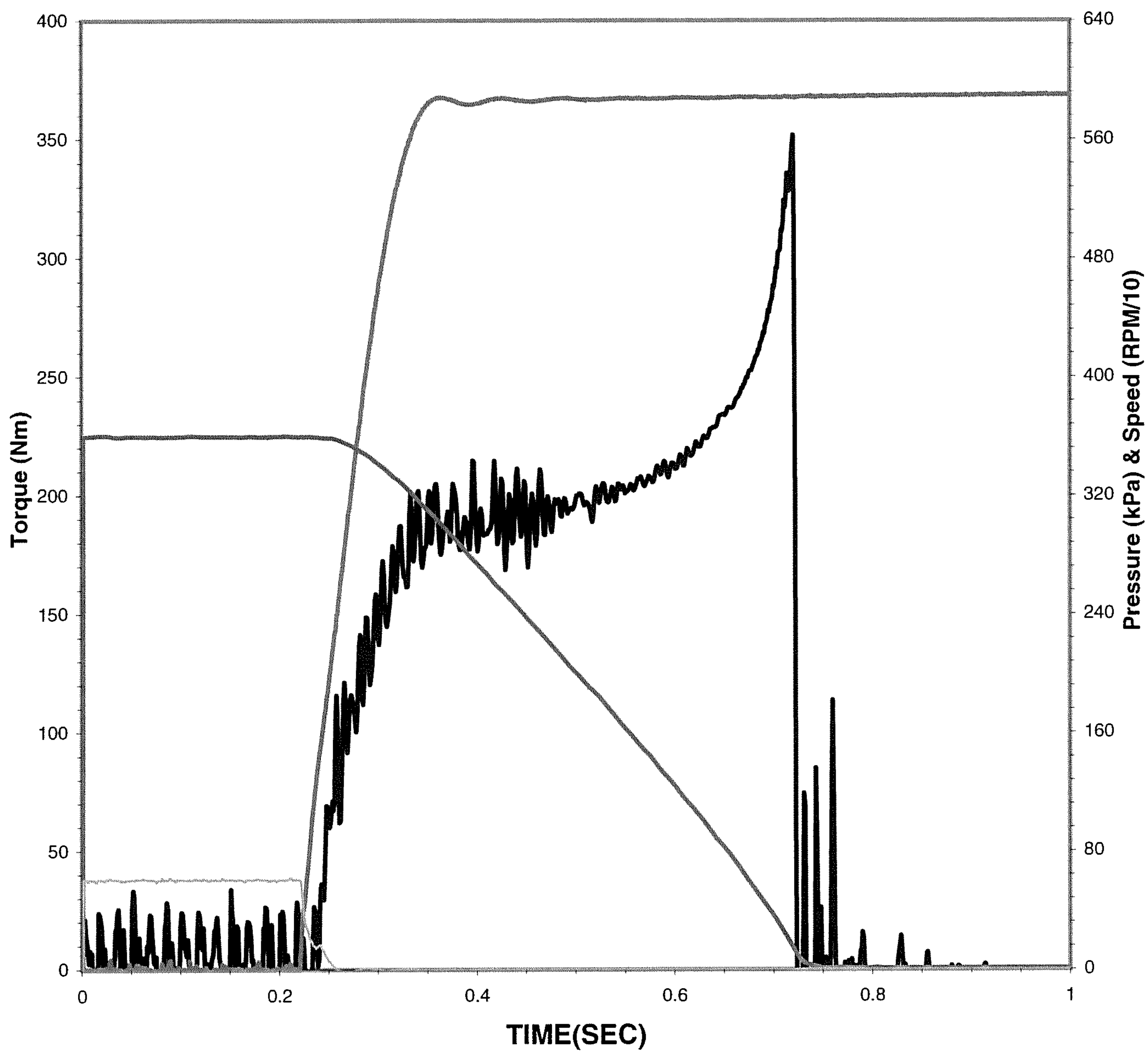
0.2 Sec Dyn:	190 N*m
Midpoint Dyn:	190 N*m
LwSpd Dynamic:	352 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.171

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	16:35:27
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	99
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.502 Sec

Torque

0.2 Sec Dyn:	194 N*m
Midpoint Dyn:	195 N*m
LwSpd Dynamic:	354 N*m

Coefficient of Friction

.2 Sec Dyn:	0.094
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.172

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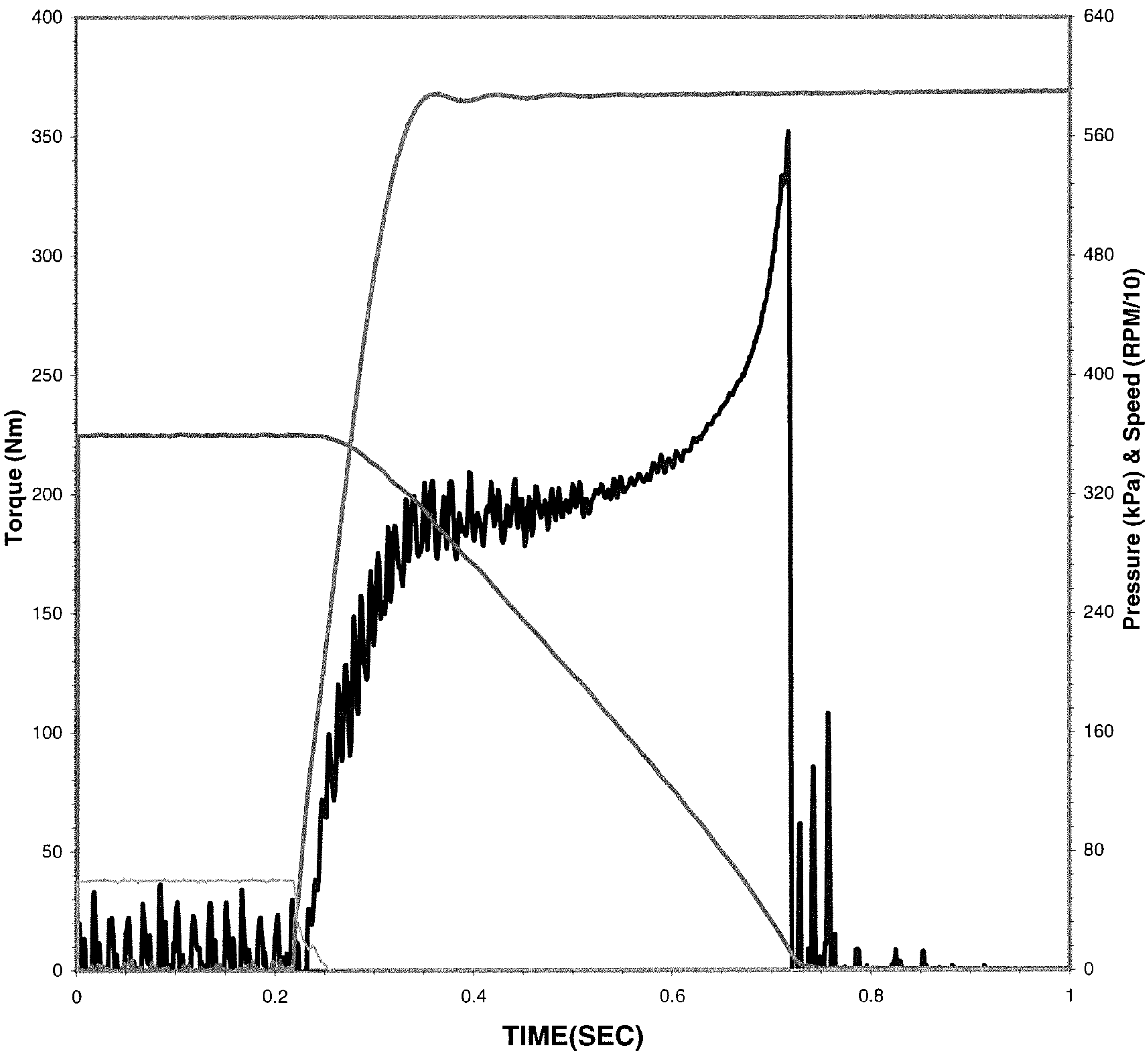
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	16:35:42
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	100
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.501 Sec

Torque

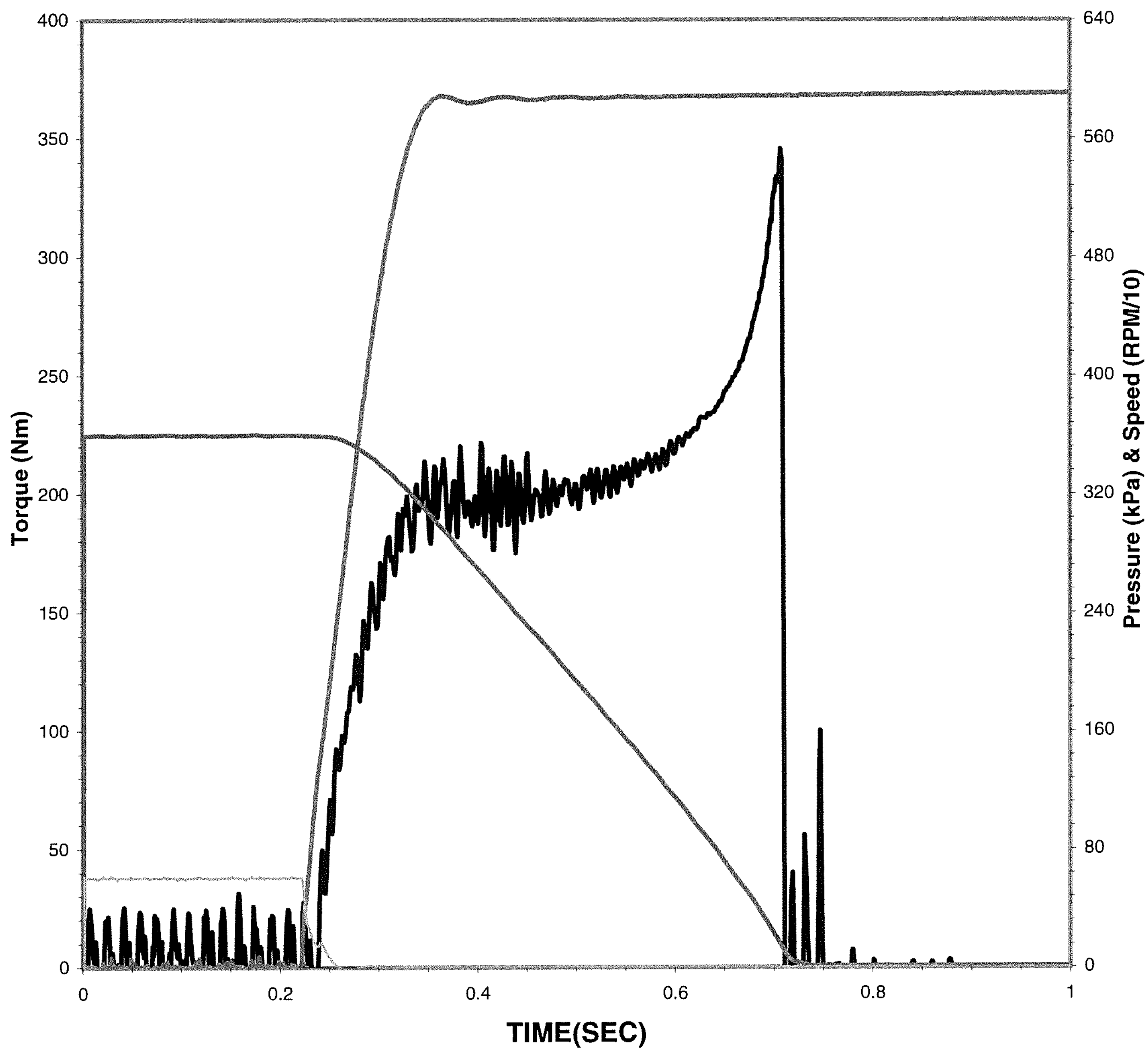
0.2 Sec Dyn:	196 N*m
Midpoint Dyn:	195 N*m
LwSpd Dynamic:	354 N*m

Coefficient of Friction

.2 Sec Dyn:	0.095
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.172

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	16:36:13
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	101
Temperature:	85.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.488 Sec

Torque

0.2 Sec Dyn:	199 N*m
Midpoint Dyn:	202 N*m
LwSpd Dynamic:	344 N*m

Coefficient of Friction

.2 Sec Dyn:	0.097
Midpoint Dyn:	0.098
LwSpd Dynamic:	0.167

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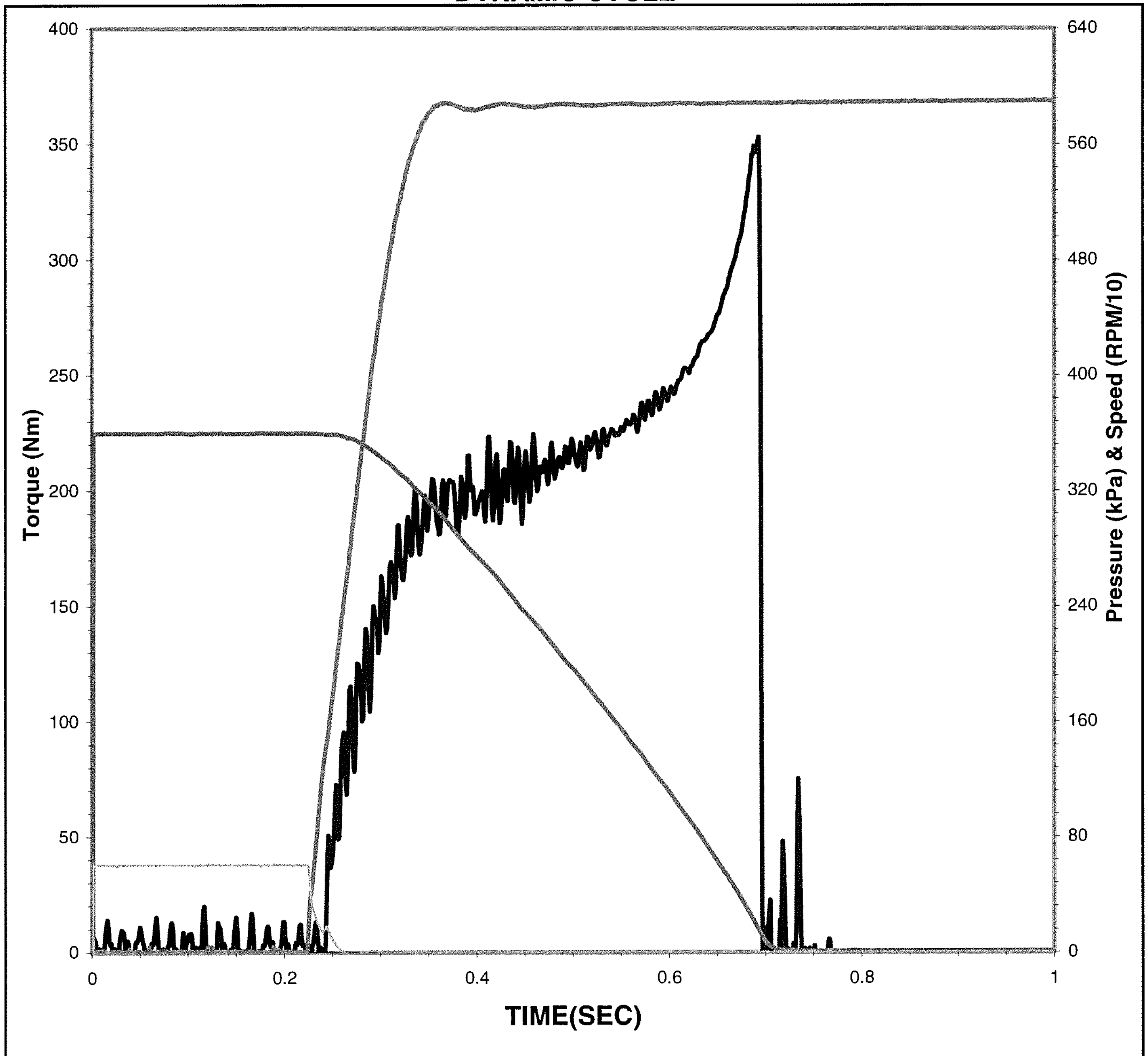
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	18:15:43
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	499
Temperature:	91.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.472 Sec

Torque

0.2 Sec Dyn:	204 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	355 N*m

Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.173

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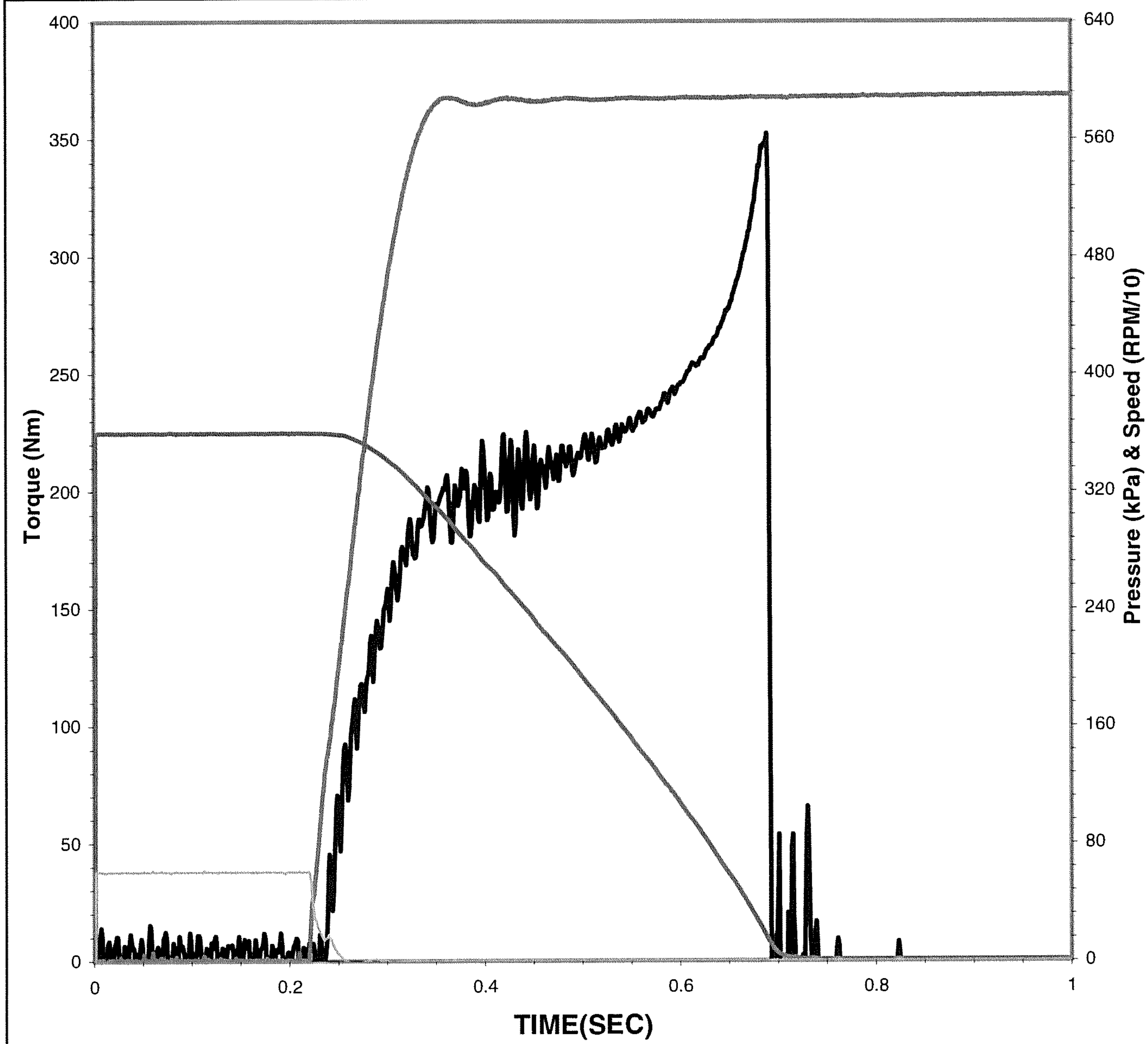
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	18:15:58
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	500
Temperature:	92.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.472 Sec

Torque

0.2 Sec Dyn:	208 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	355 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.173

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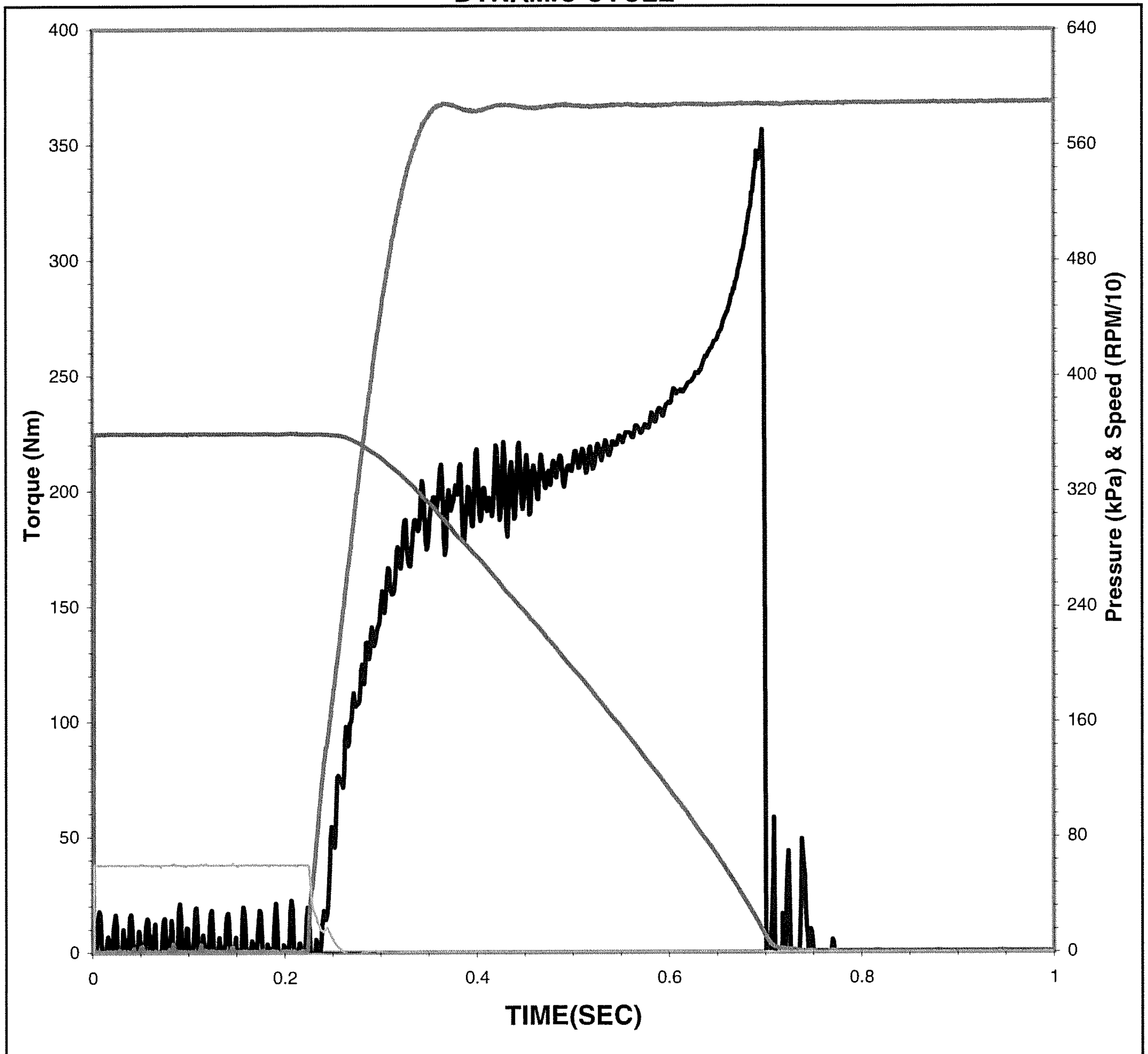
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	18:16:29
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	501
Temperature:	85.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.476 Sec

Torque

0.2 Sec Dyn:	204 N*m
Midpoint Dyn:	207 N*m
LwSpd Dynamic:	359 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.175

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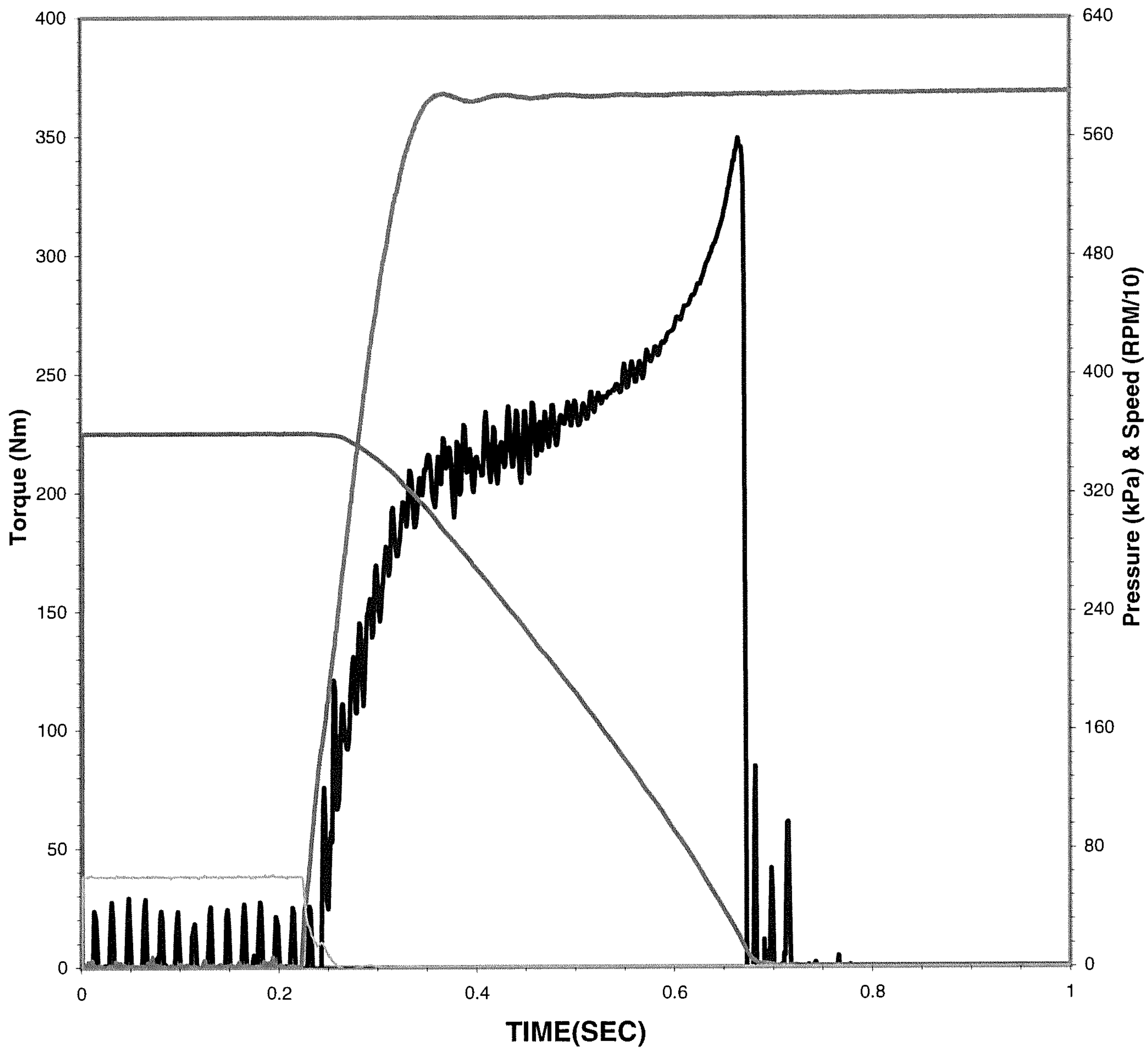
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	20:20:59
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	999
Temperature:	91.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.449 Sec

Torque

0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	344 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.168

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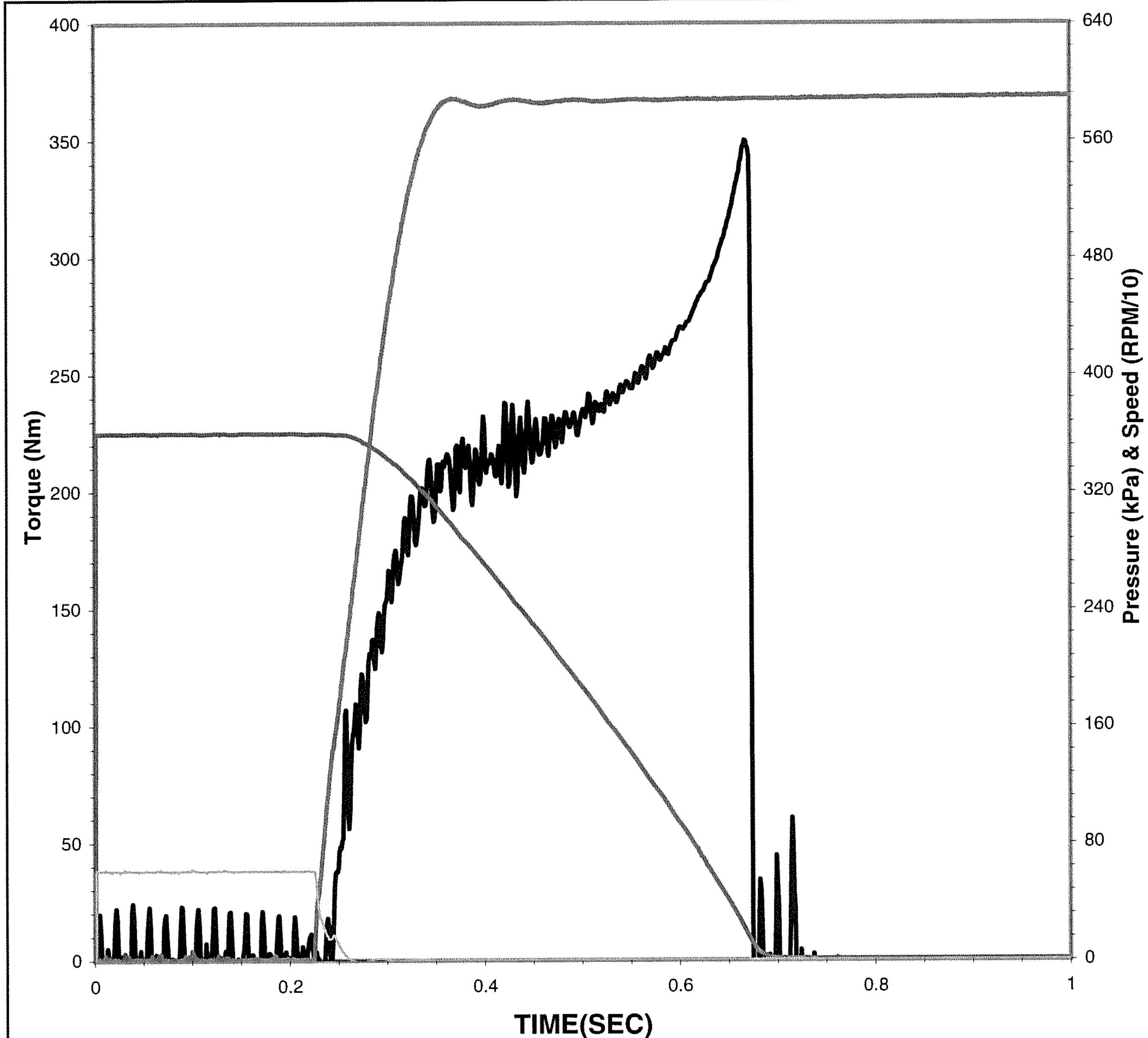
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	20:21:14
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	1000
Temperature:	91.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.449 Sec

Torque

0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	346 N*m

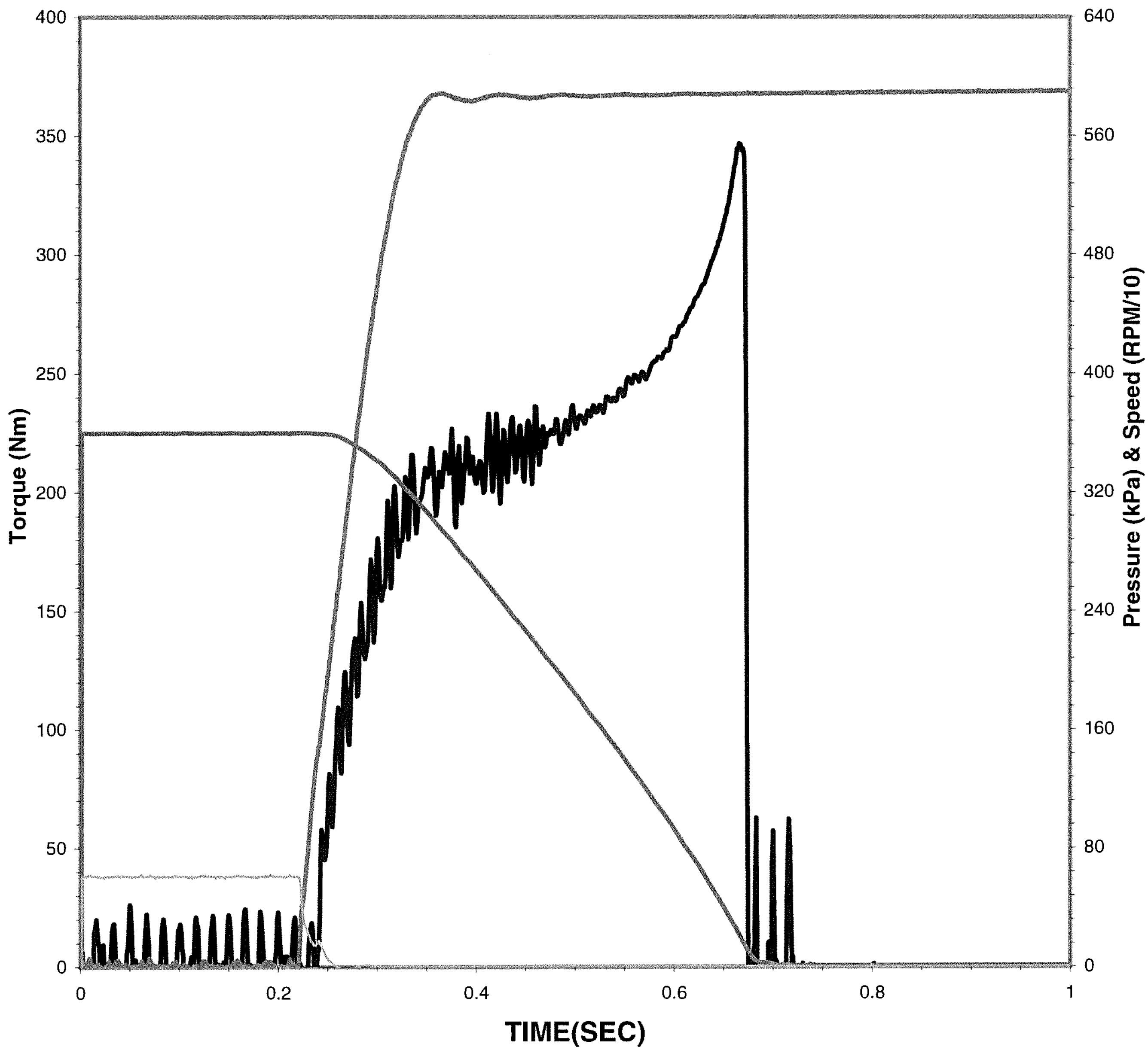
Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.168

A 73

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/27/2014
Time of Test:	20:21:46
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	1001
Temperature:	85.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.453 Sec

Torque

0.2 Sec Dyn:	216 N*m
Midpoint Dyn:	221 N*m
LwSpd Dynamic:	343 N*m

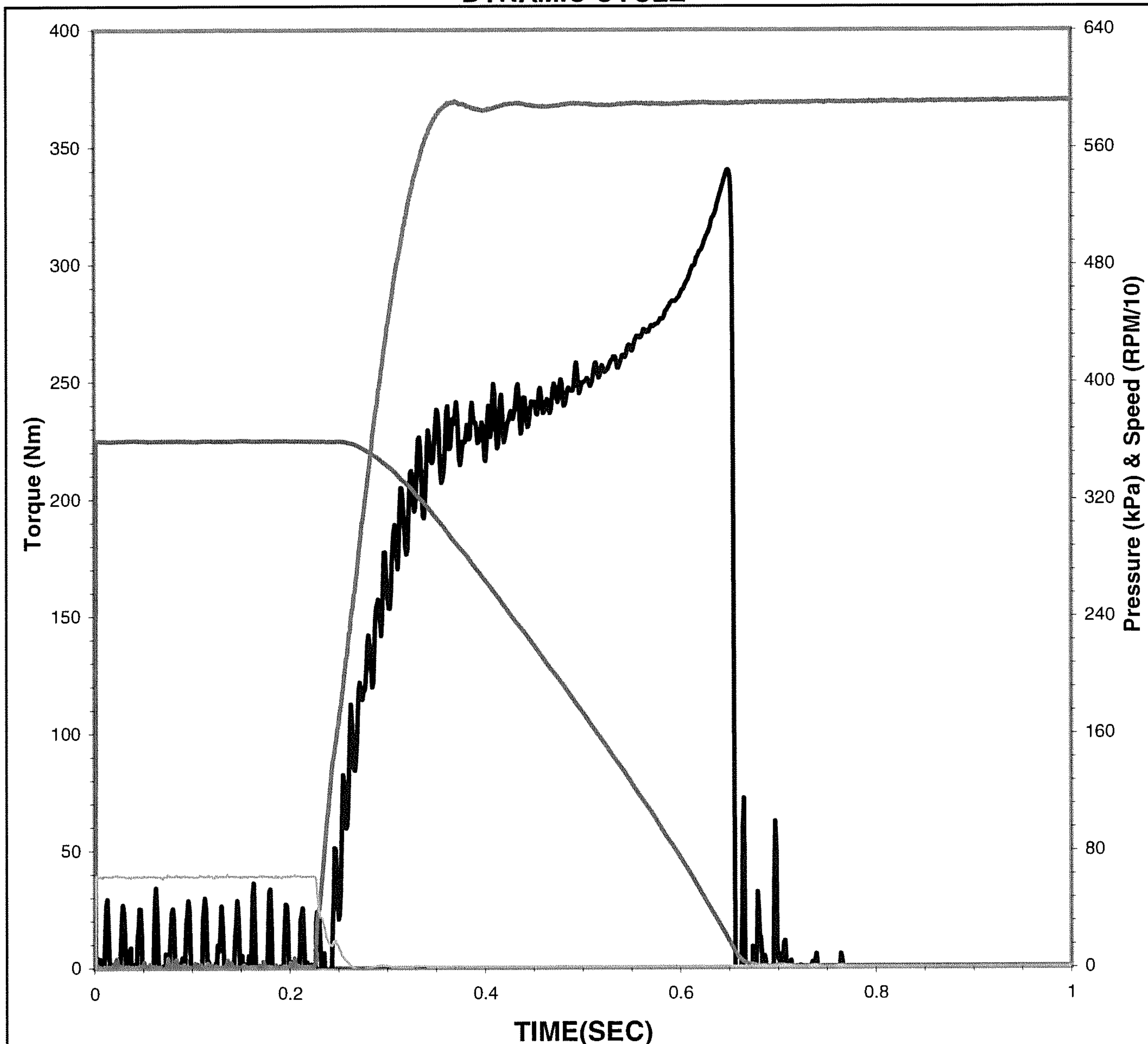
Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.167

A 74

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	2:36:16
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	2499
Temperature:	92.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.429 Sec

Torque

0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	333 N*m

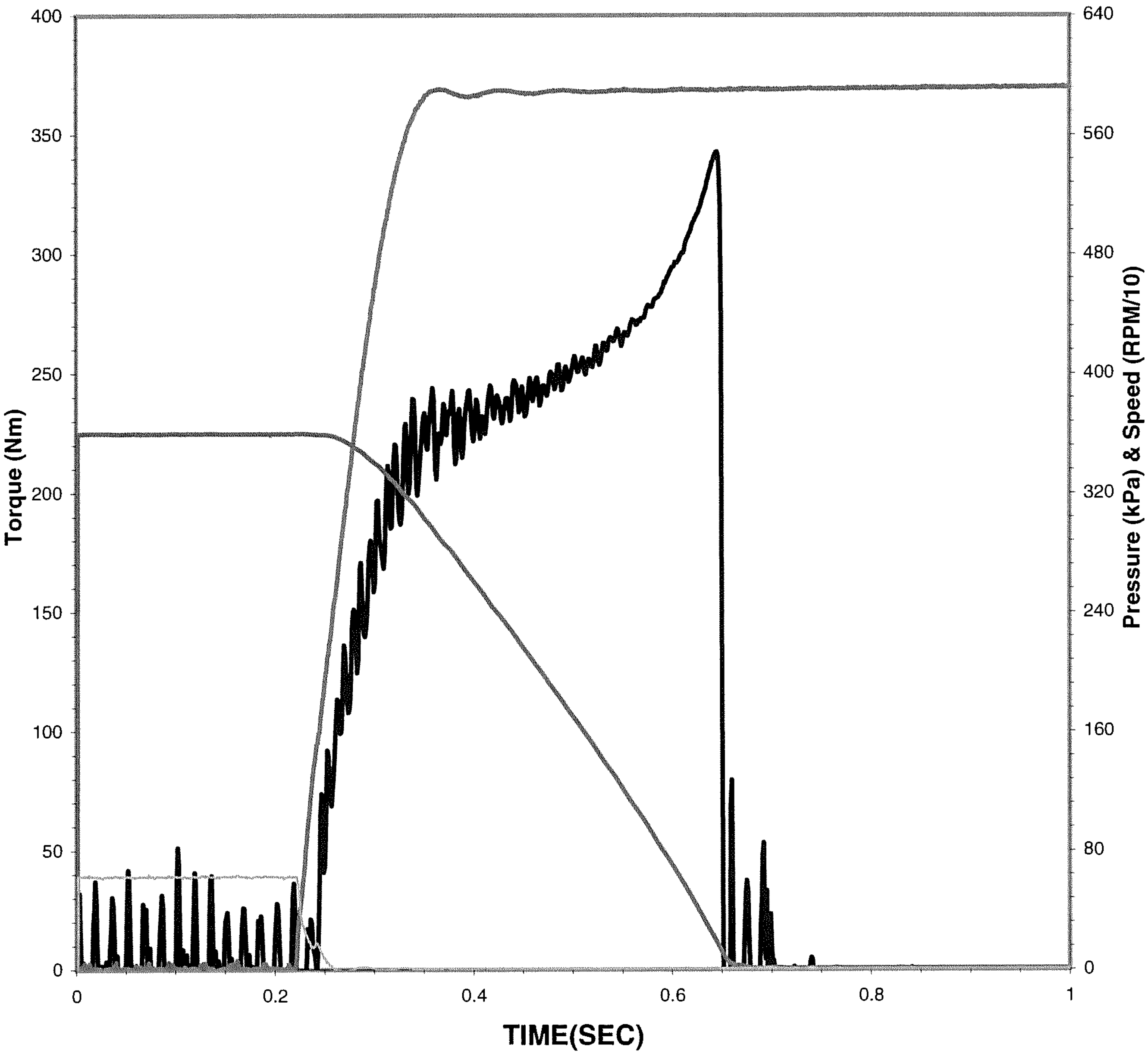
Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.162

A 75

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	2:36:31
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	2500
Temperature:	92.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.428 Sec

Torque

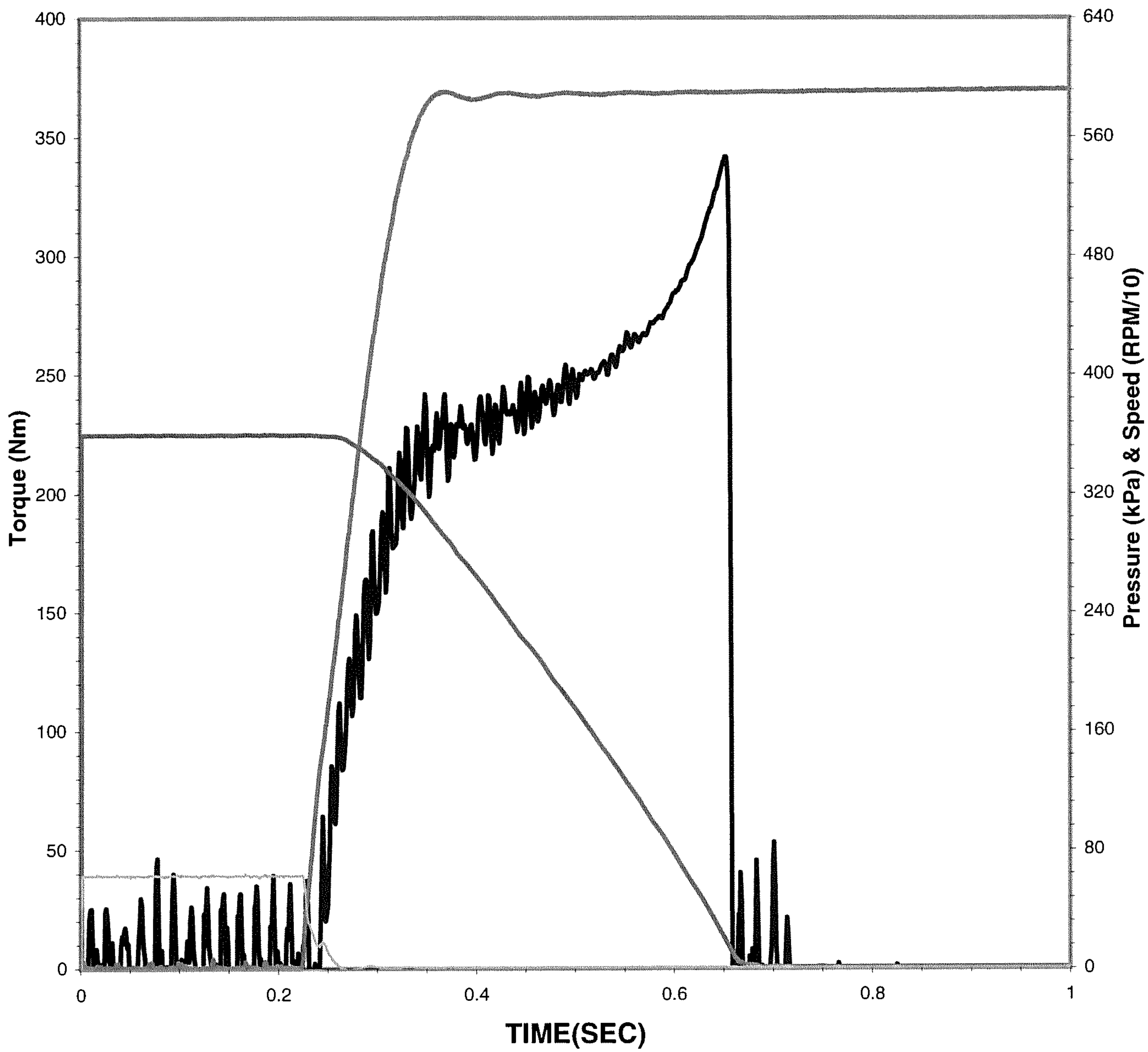
0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	240 N*m
LwSpd Dynamic:	338 N*m

Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.164

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	2:37:02
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	2501
Temperature:	86.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.433 Sec

Torque

0.2 Sec Dyn:	235 N*m
Midpoint Dyn:	236 N*m
LwSpd Dynamic:	333 N*m

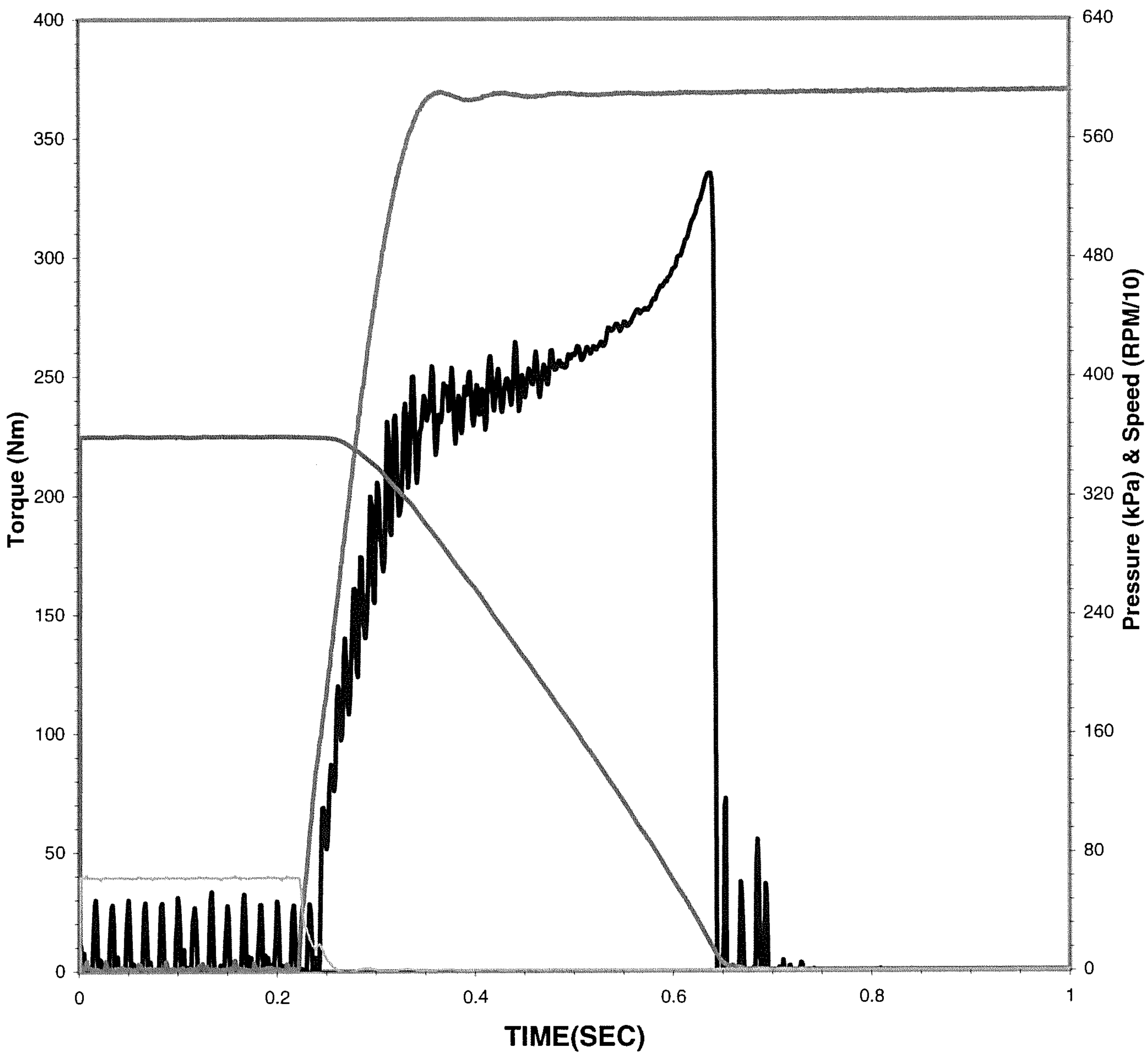
Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.162

A 77

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	13:01:32
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	4999
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.421 Sec

Torque

0.2 Sec Dyn:	246 N*m
Midpoint Dyn:	247 N*m
LwSpd Dynamic:	328 N*m

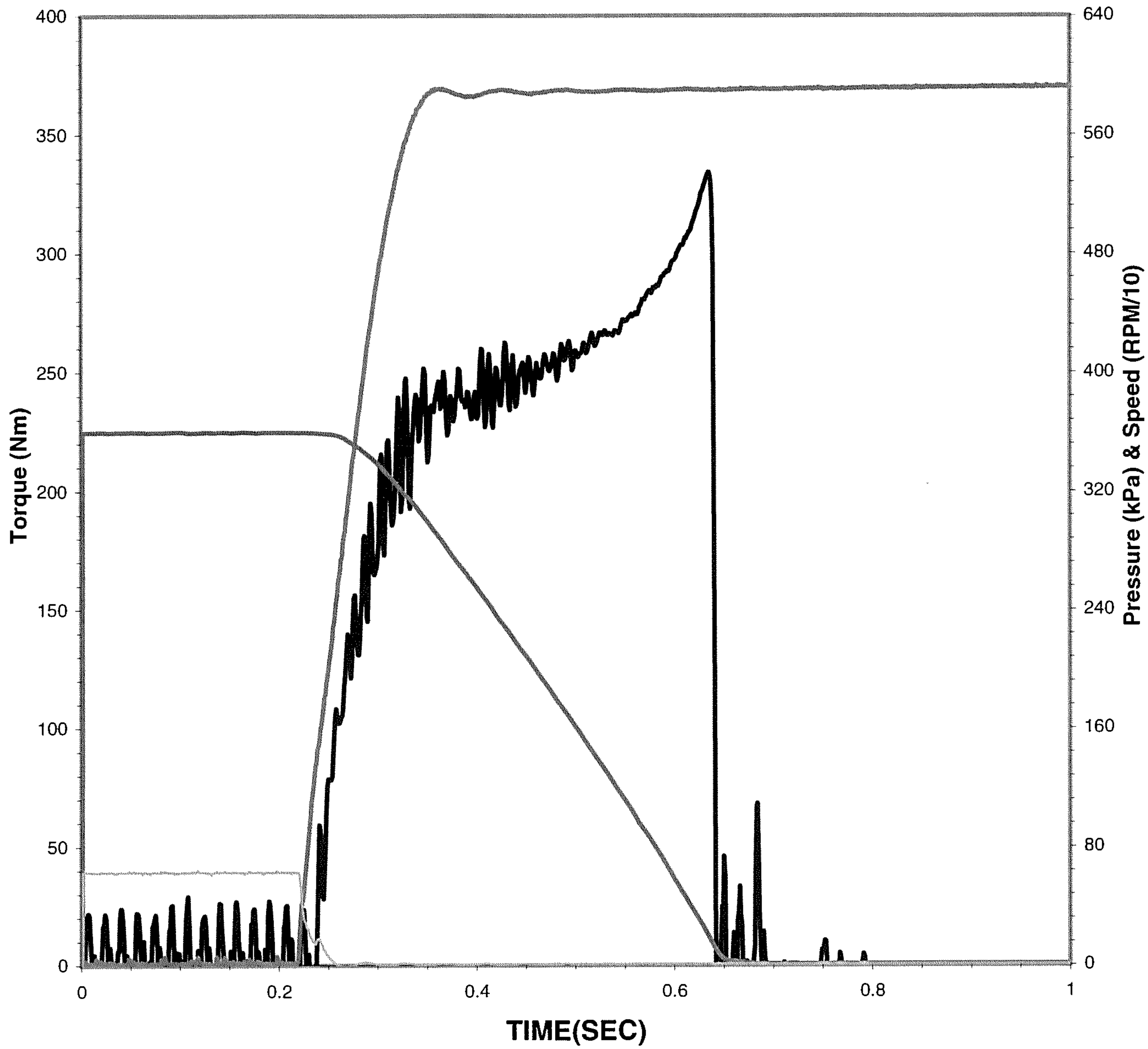
Coefficient of Friction

.2 Sec Dyn:	0.120
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.160

A 78

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	13:01:47
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	5000
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.8 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.421 Sec

Torque

0.2 Sec Dyn:	246 N*m
Midpoint Dyn:	247 N*m
LwSpd Dynamic:	323 N*m

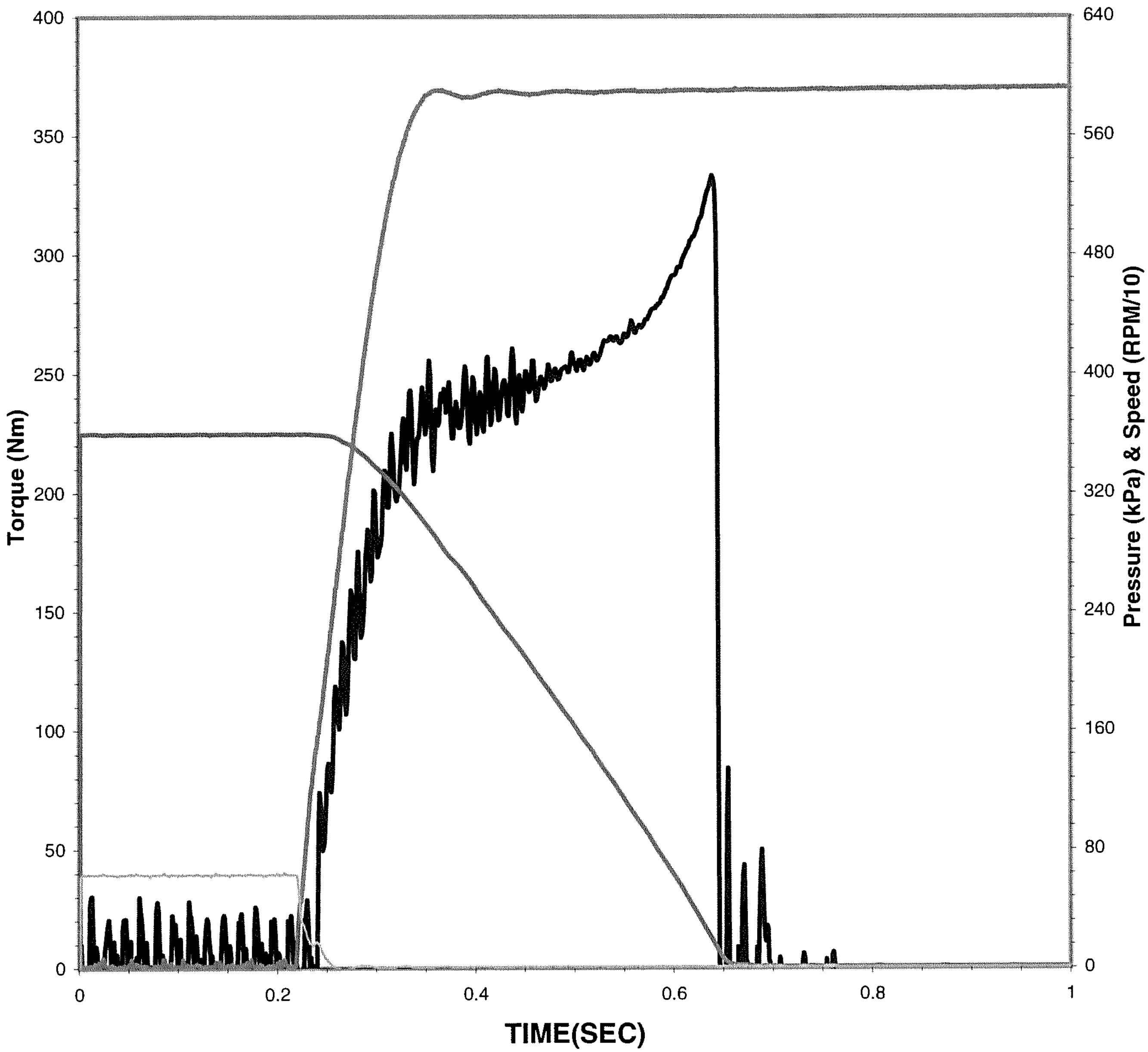
Coefficient of Friction

.2 Sec Dyn:	0.120
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.157

A 79

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	13:02:18
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	5001
Temperature:	85.8 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	588 kPa
	(586 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.7 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.426 Sec

Torque

0.2 Sec Dyn:	242 N*m
Midpoint Dyn:	243 N*m
LwSpd Dynamic:	327 N*m

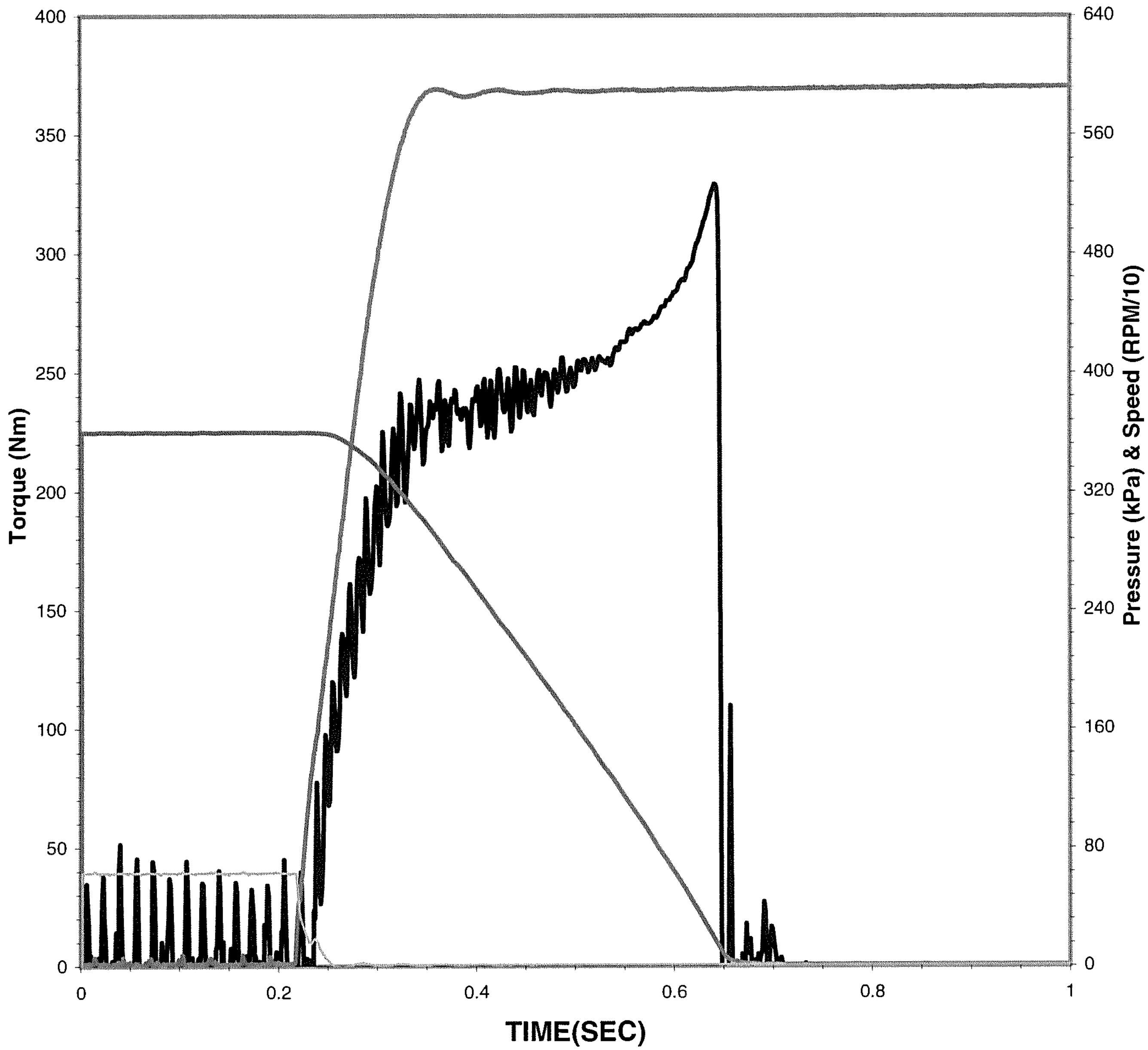
Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.159

08 V

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	23:26:48
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	7499
Temperature:	92.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.43 Sec

Torque

0.2 Sec Dyn:	239 N*m
Midpoint Dyn:	241 N*m
LwSpd Dynamic:	324 N*m

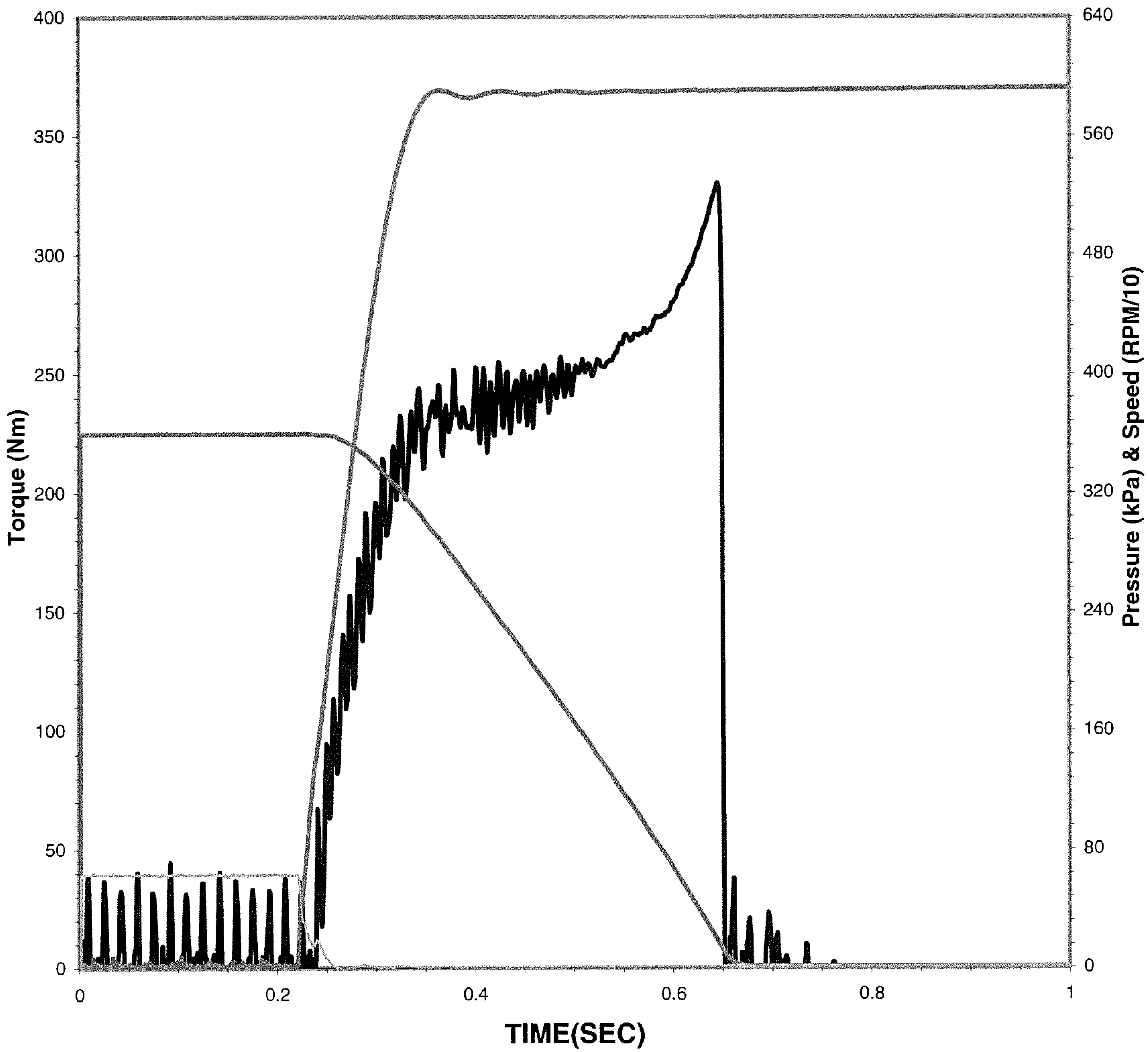
Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.158

A 81

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



A 82

Date of Test:	1/28/2014
Time of Test:	23:27:03
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	7500
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.43 Sec

Torque

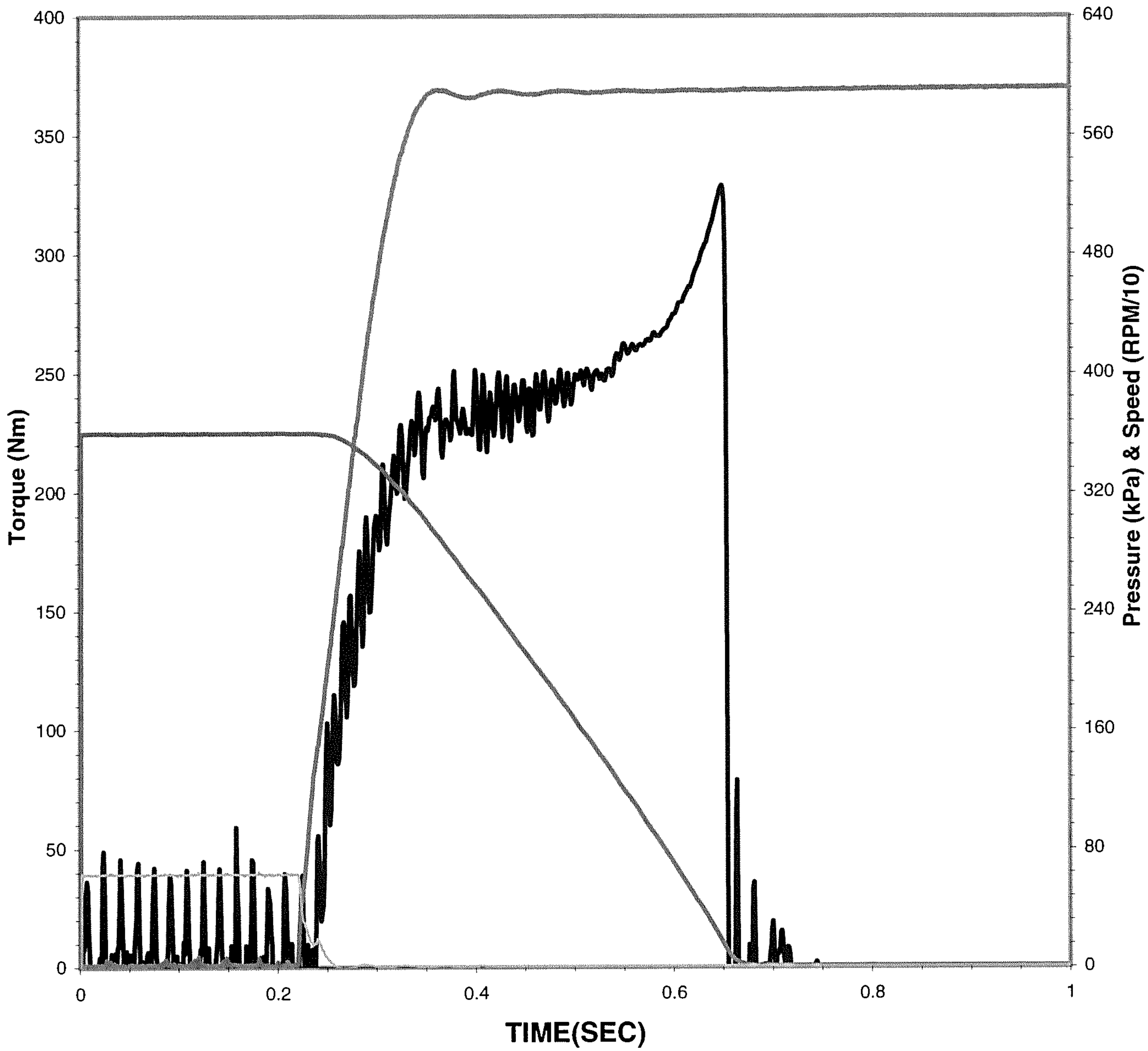
0.2 Sec Dyn:	240 N*m
Midpoint Dyn:	240 N*m
LwSpd Dynamic:	326 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.159

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/28/2014
Time of Test:	23:27:34
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	7501
Temperature:	86.4 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	588 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.7 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.434 Sec

Torque

0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	237 N*m
LwSpd Dynamic:	323 N*m

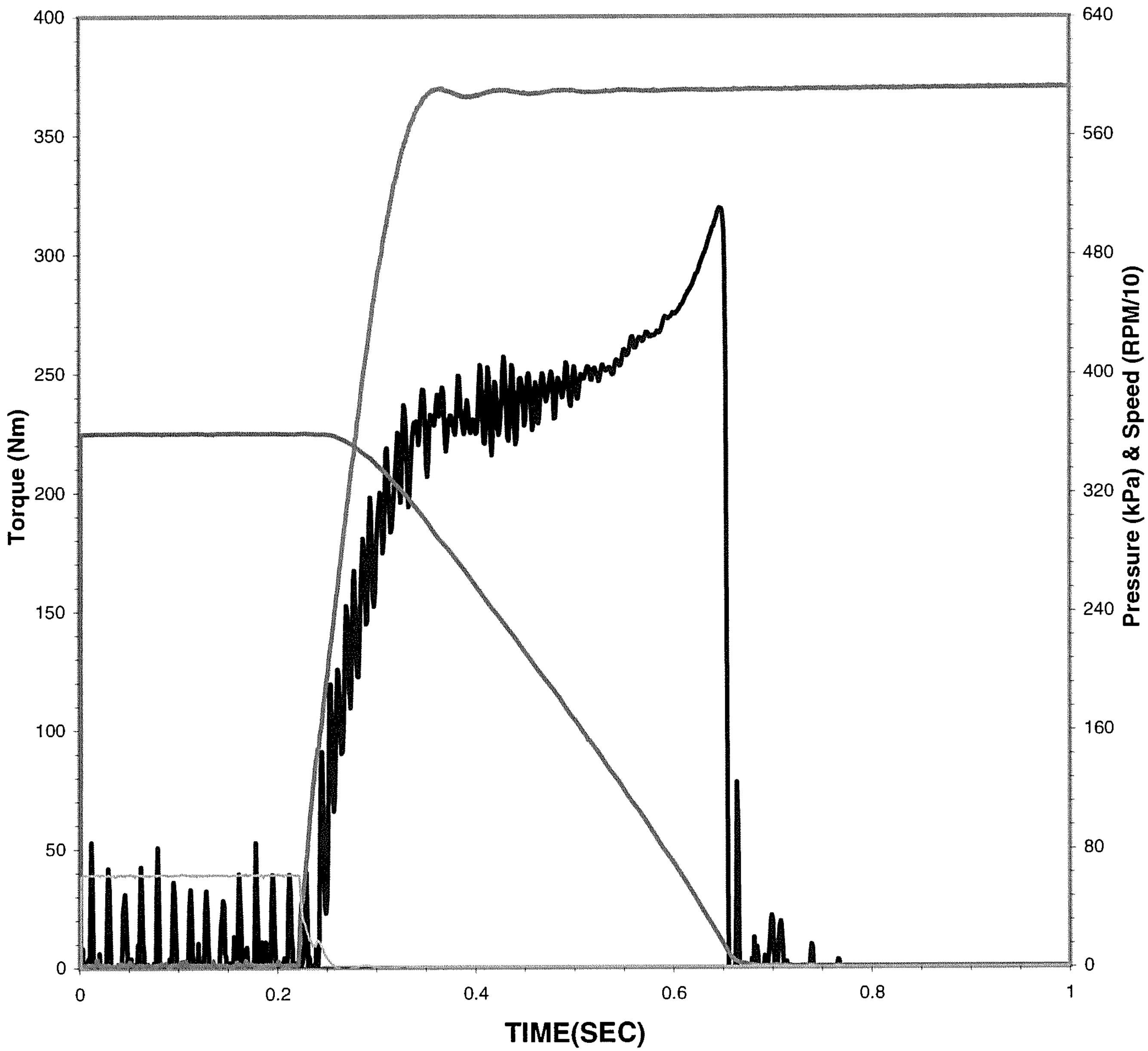
Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.157

A 83

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/29/2014
Time of Test:	9:51:50
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	9998
Temperature:	92.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.433 Sec

Torque

0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	311 N*m

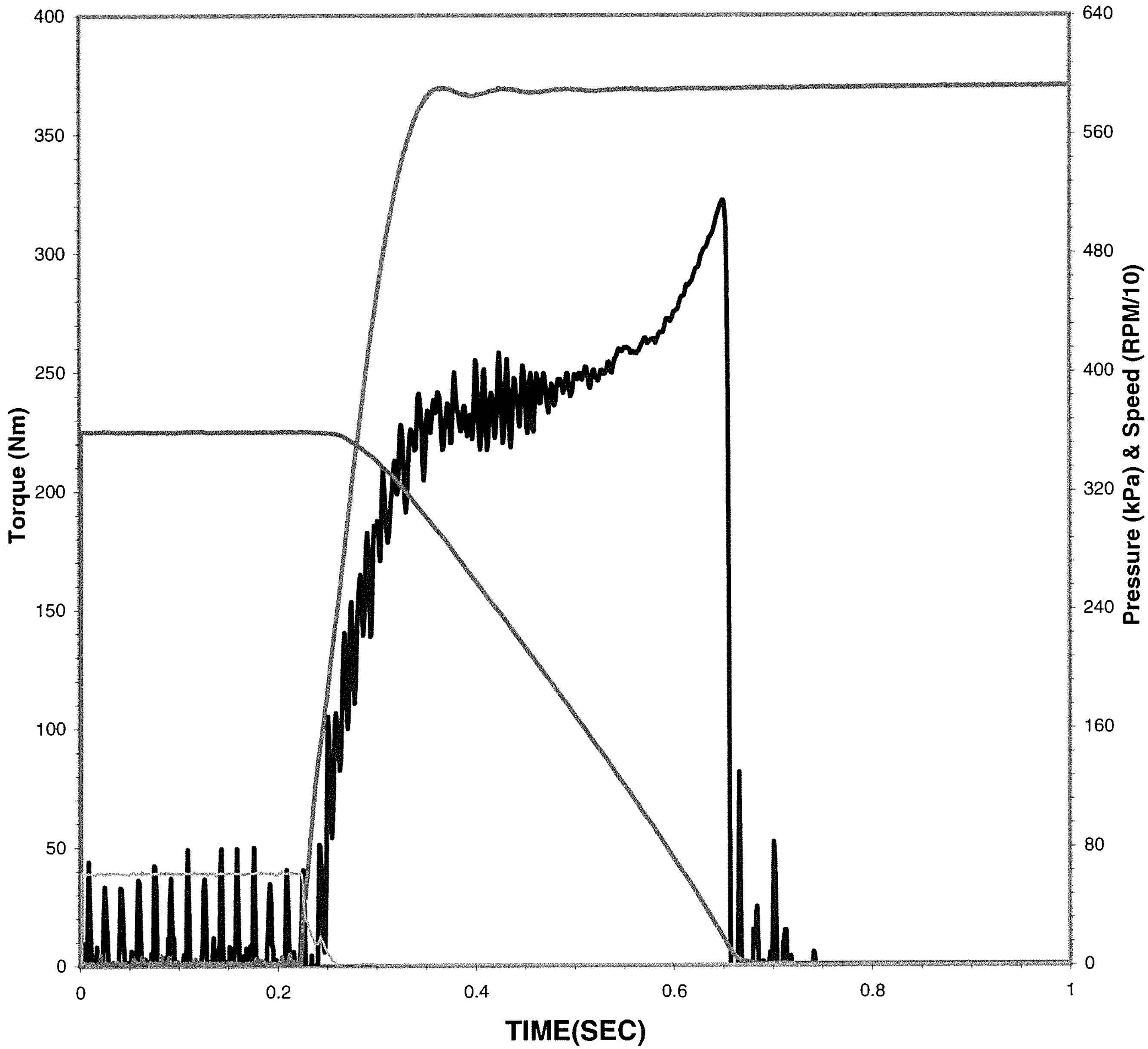
Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.152

A 84

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/29/2014
Time of Test:	9:52:05
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	9999
Temperature:	91.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.433 Sec

Torque

0.2 Sec Dyn:	240 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	313 N*m

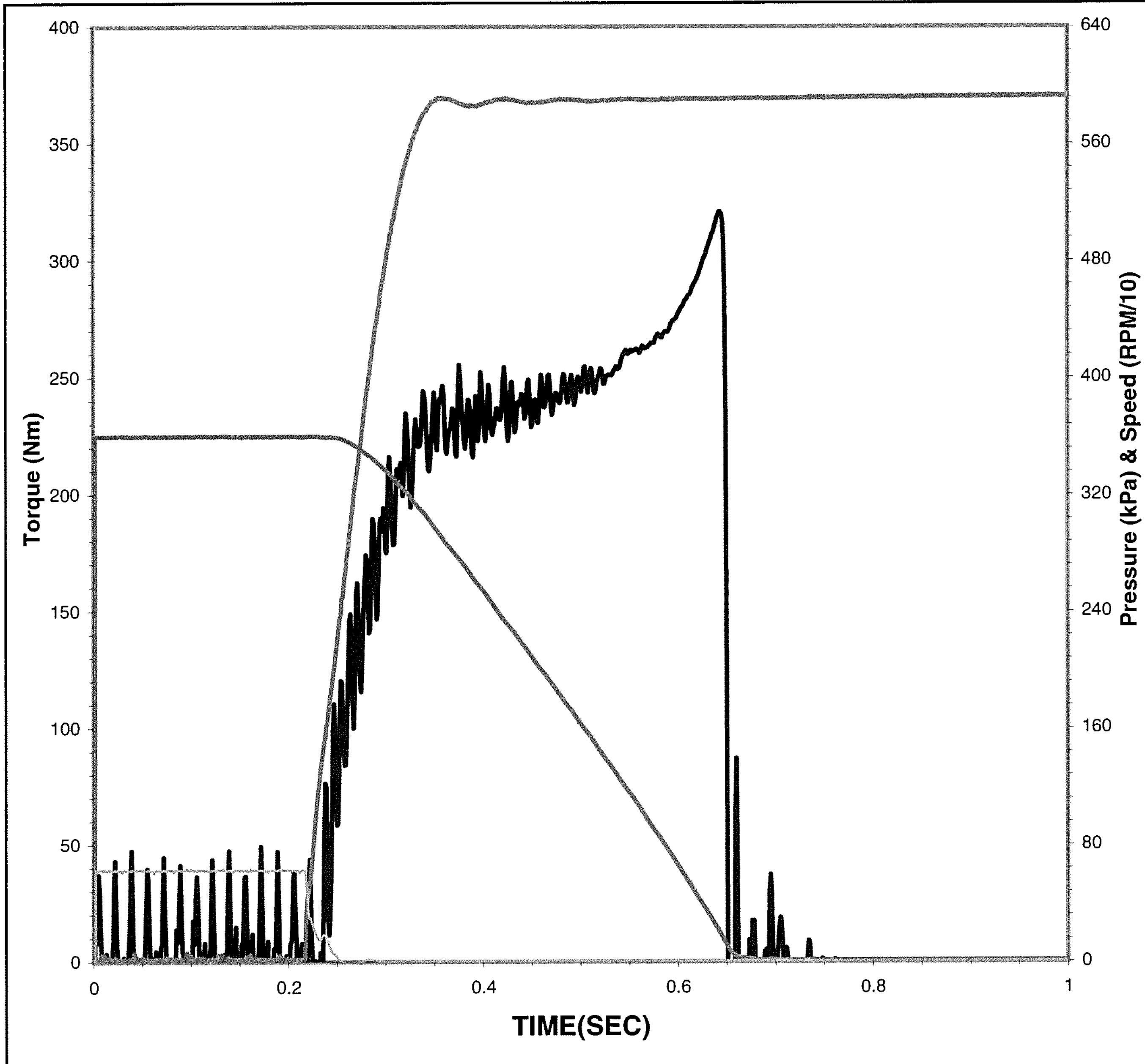
Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.152

A 85

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	1/29/2014
Time of Test:	9:52:20
Test Number:	C2-7-1615
Fluid Code:	LO292039
Cycle Number:	10000
Temperature:	91.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.434 Sec

Torque

0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	238 N*m
LwSpd Dynamic:	310 N*m

Coefficient of Friction

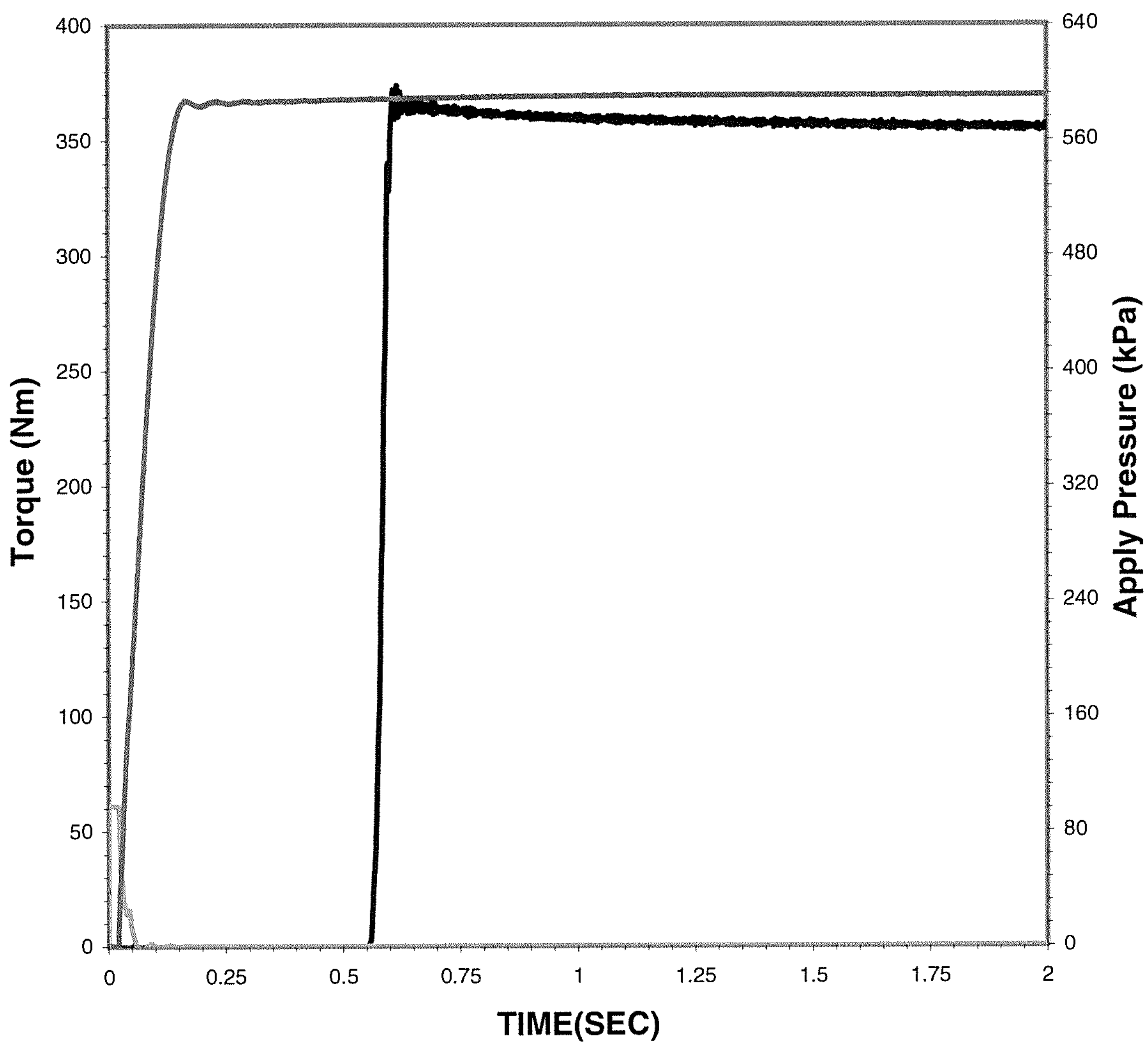
.2 Sec Dyn:	0.116
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.151

98 V

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 1/27/2014

Time of Test: 16:13:12

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 10

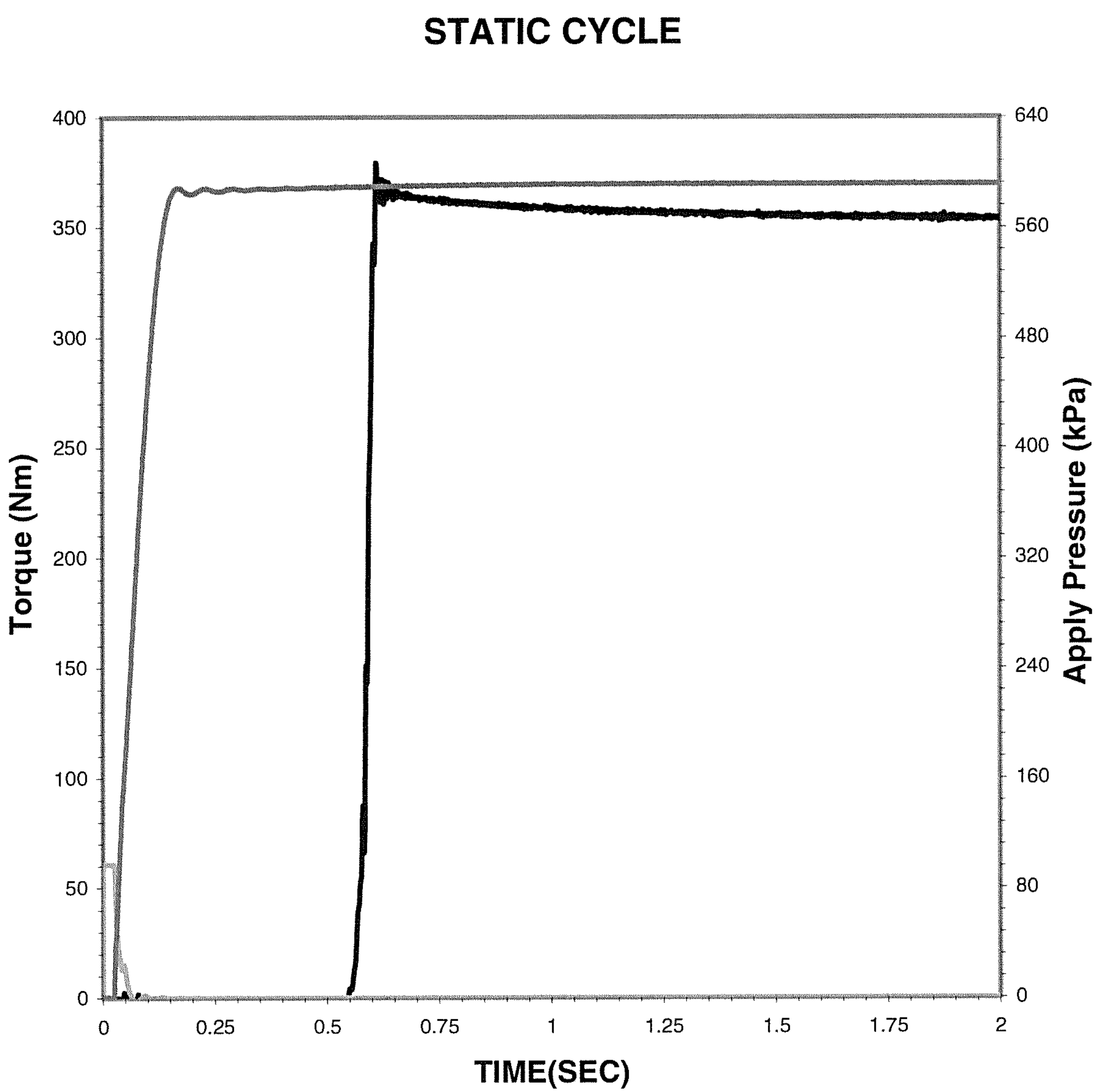
STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 376 Nm
.25 Second: 364 Nm

Coefficient of Friction
Static Peak: 0.183
.25 Second: 0.177

ALLISON C-4 PAPER DATA



Date of Test: 1/27/2014

Time of Test: 16:35:58

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 100

STATIC CYCLE

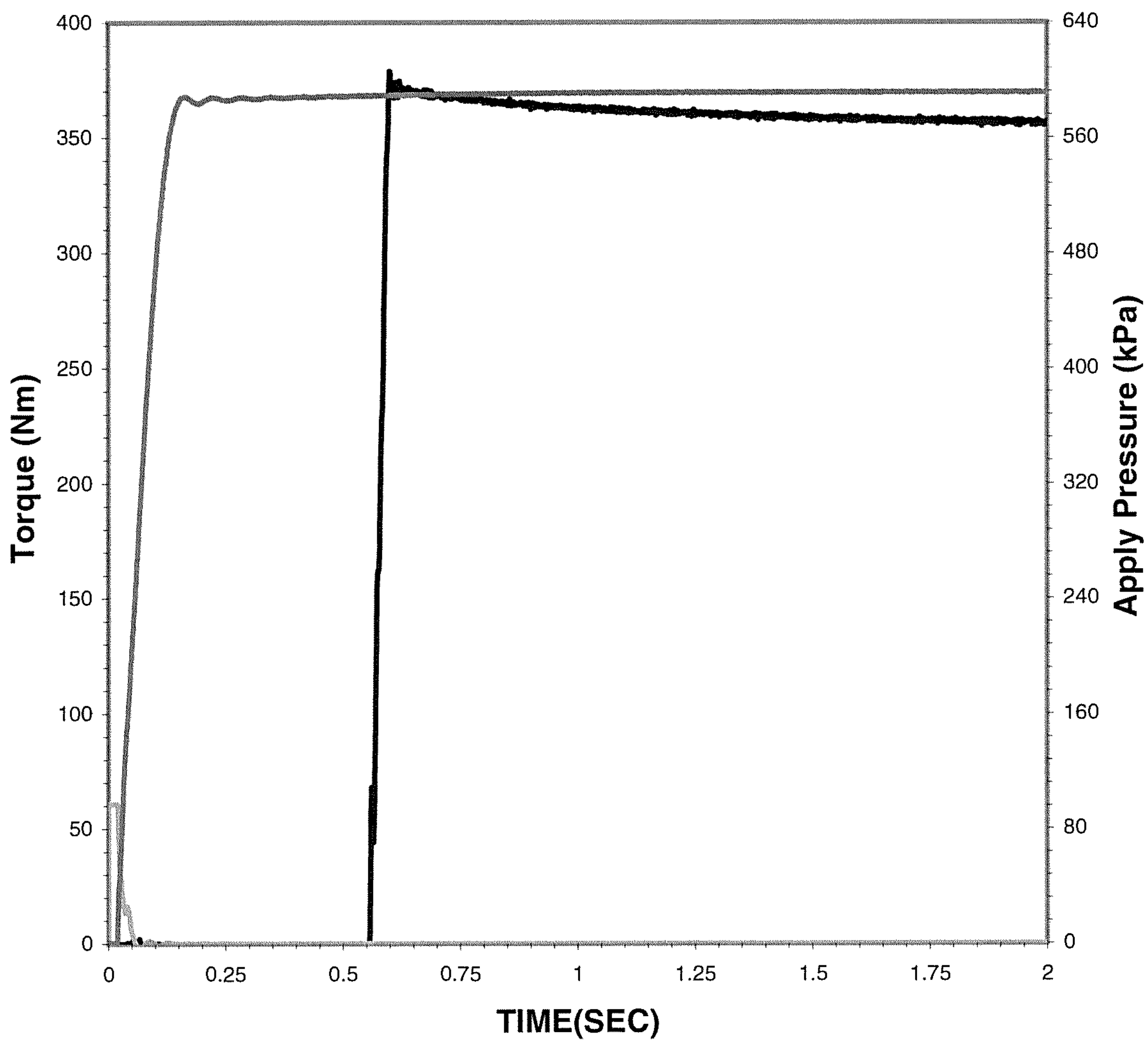
Apply Pressure:
At .25 Second: 587 kPa

Torque
Static Peak: 380 Nm
.25 Second: 362 Nm

Coefficient of Friction
Static Peak: 0.185
.25 Second: 0.176

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 1/27/2014

Time of Test: 18:16:14

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 500

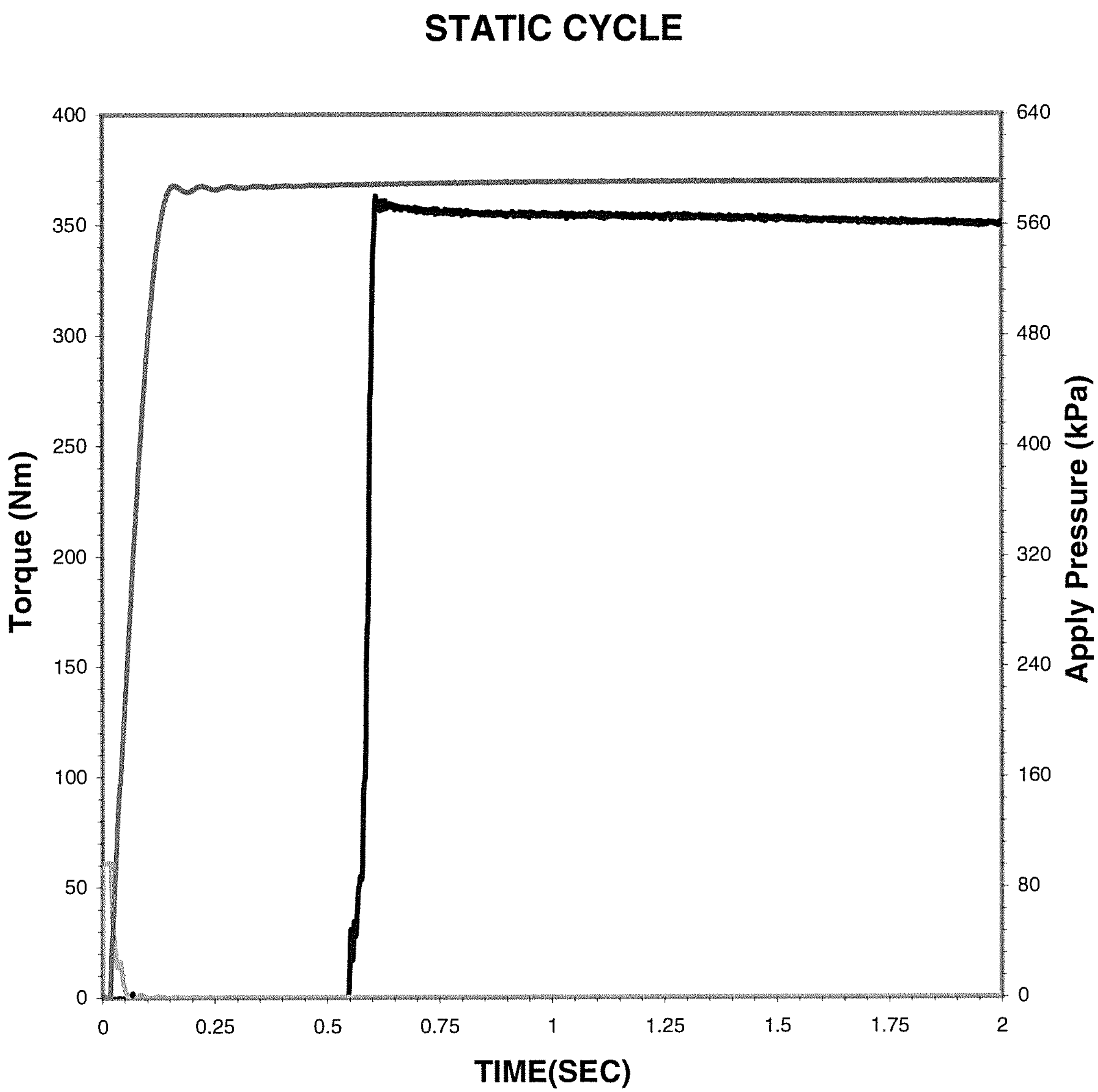
STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 380 Nm
.25 Second: 367 Nm

Coefficient of Friction
Static Peak: 0.185
.25 Second: 0.179

ALLISON C-4 PAPER DATA



Date of Test: 1/27/2014

Time of Test: 20:21:30

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 1000

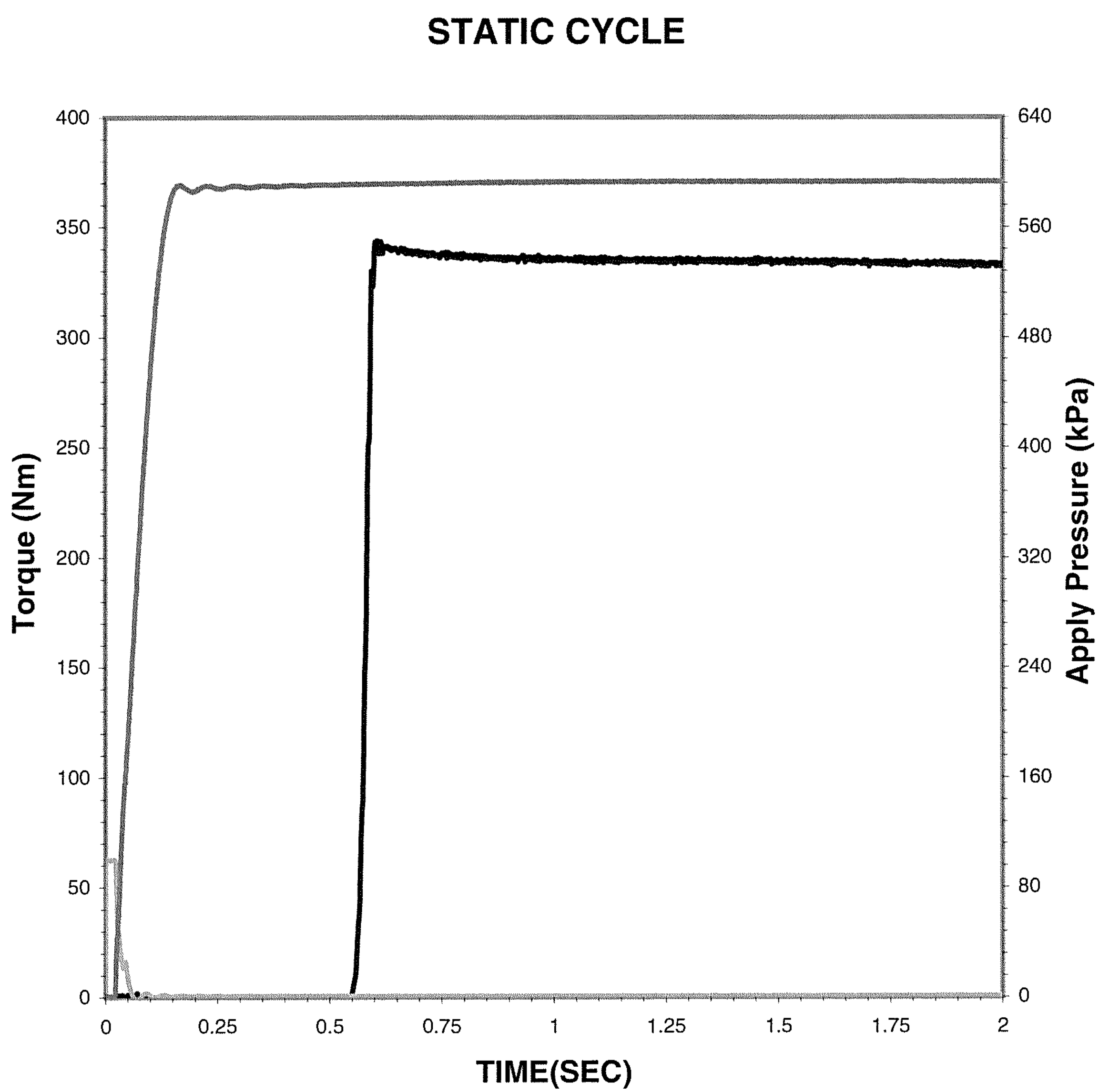
STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 364 Nm
.25 Second: 358 Nm

Coefficient of Friction
Static Peak: 0.177
.25 Second: 0.174

ALLISON C-4 PAPER DATA



Date of Test: 1/28/2014

Time of Test: 2:36:47

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 2500

STATIC CYCLE

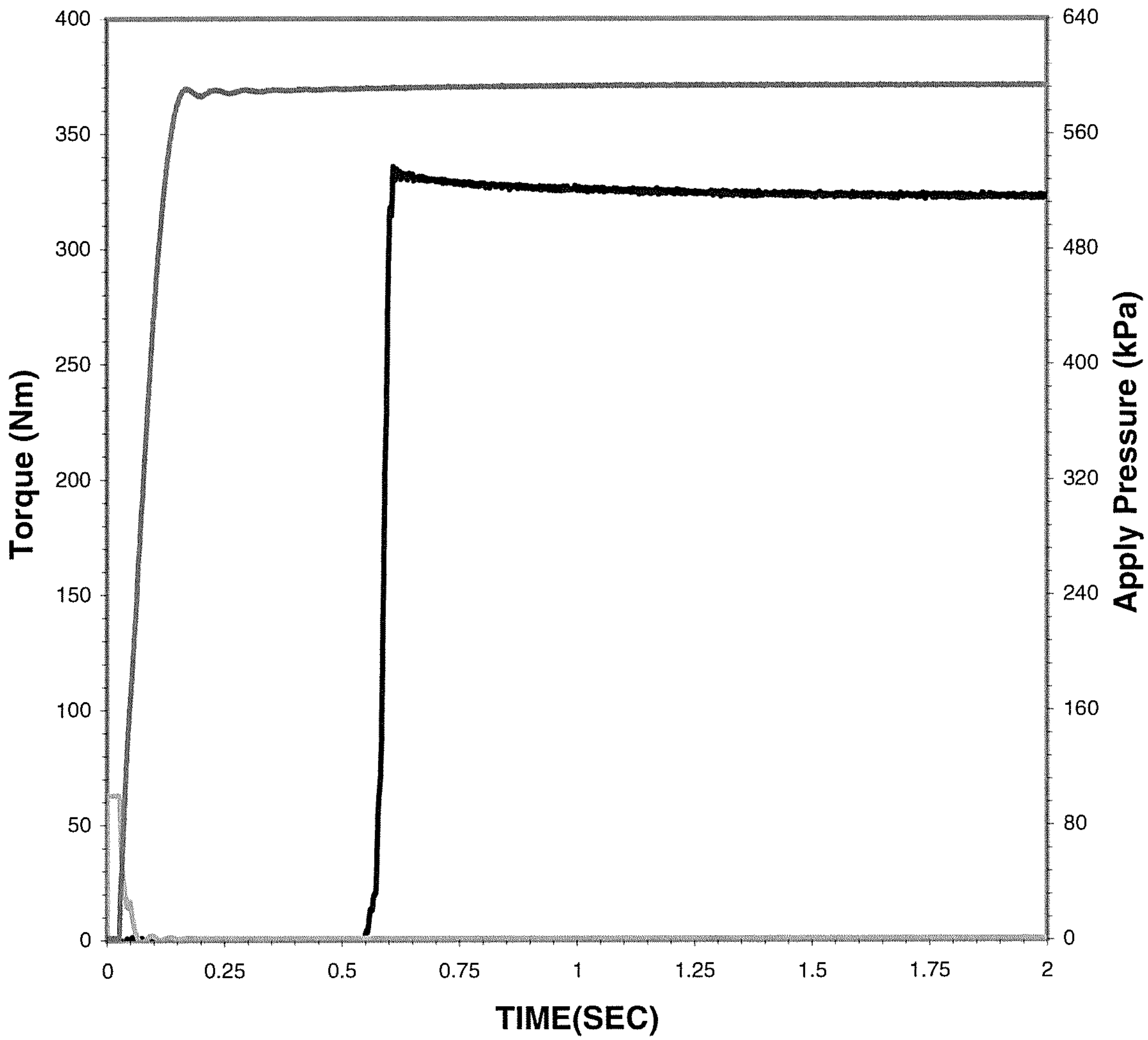
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 344 Nm
.25 Second: 338 Nm

Coefficient of Friction
Static Peak: 0.168
.25 Second: 0.164

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 1/28/2014

Time of Test: 13:02:03

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 5000

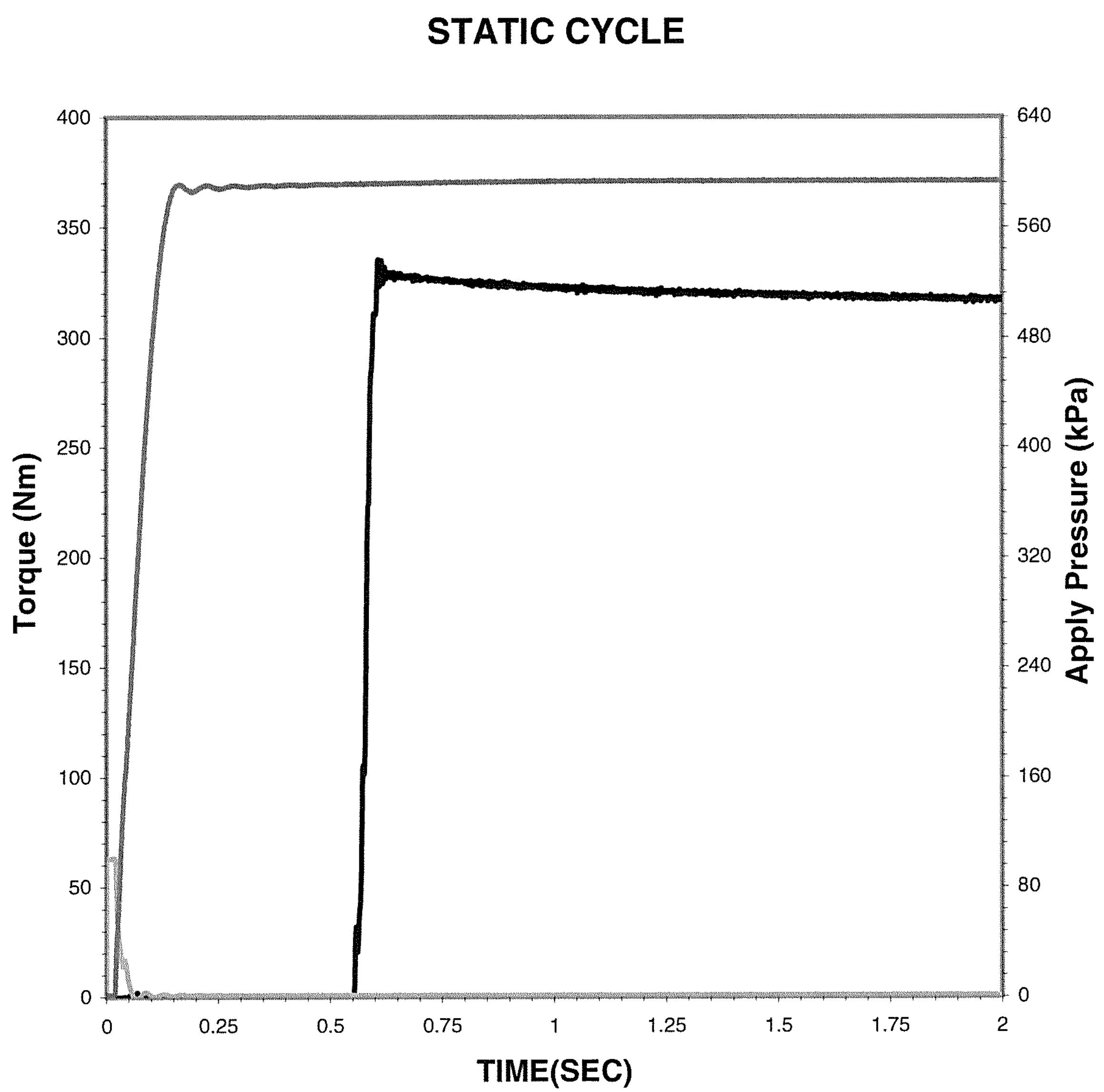
STATIC CYCLE

Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 337 Nm
.25 Second: 328 Nm

Coefficient of Friction
Static Peak: 0.164
.25 Second: 0.160

ALLISON C-4 PAPER DATA



Date of Test: 1/28/2014

Time of Test: 23:27:19

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 7500

STATIC CYCLE

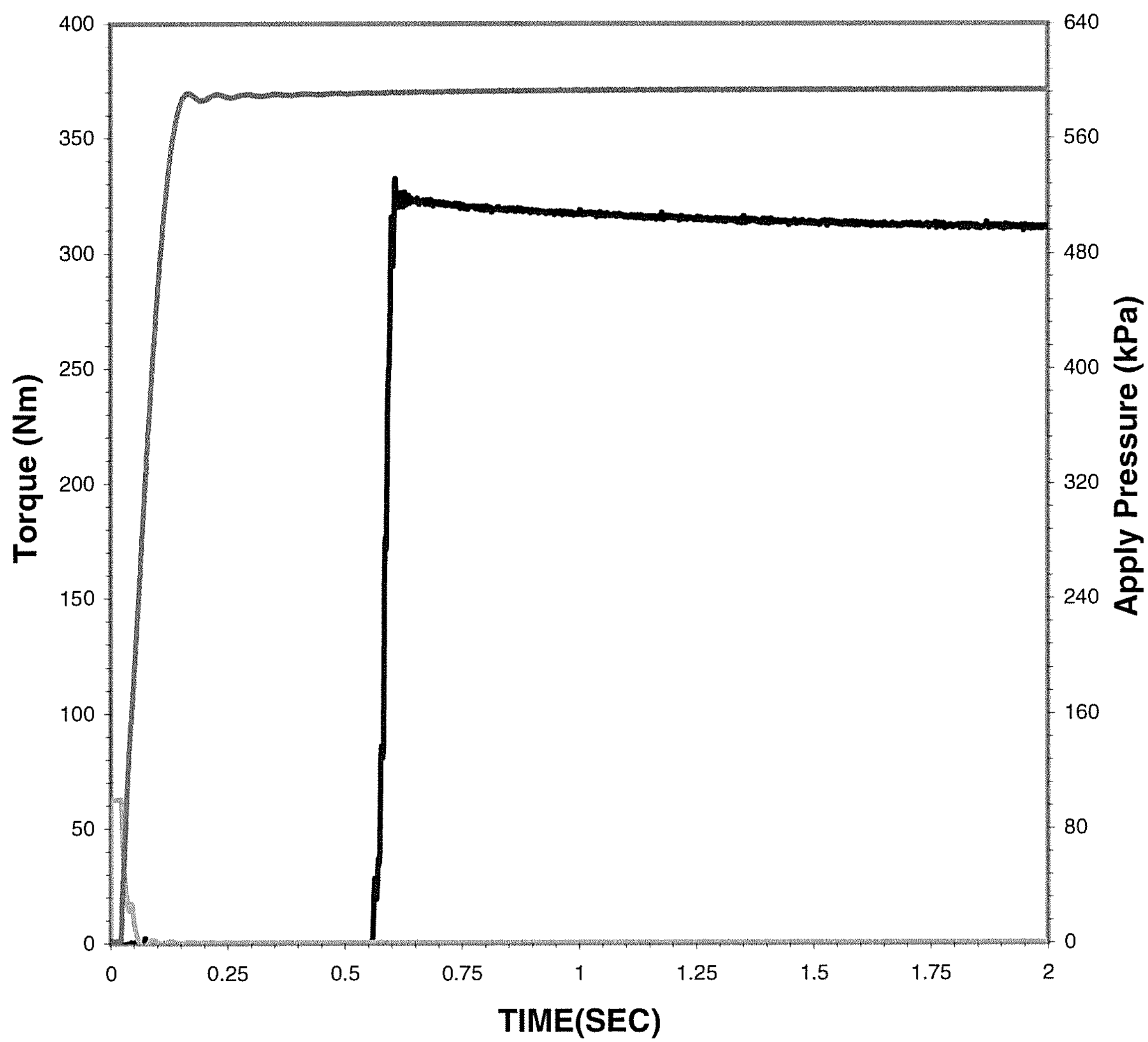
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 336 Nm
.25 Second: 325 Nm

Coefficient of Friction
Static Peak: 0.164
.25 Second: 0.158

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 1/29/2014

Time of Test: 9:52:36

Test Number: C2-7-1615

Fluid Code: LO292039

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 333 Nm
.25 Second: 321 Nm

Coefficient of Friction
Static Peak: 0.162
.25 Second: 0.156

A-95

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
SEQUENCE 1220 ONLY

Conducted for

ARMY LAB

Oil Code:
LO292039

Test Number:
A-109-I

February 11, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 2/11/2014
End of test date: 2/11/2014
Oil Code: LO292039

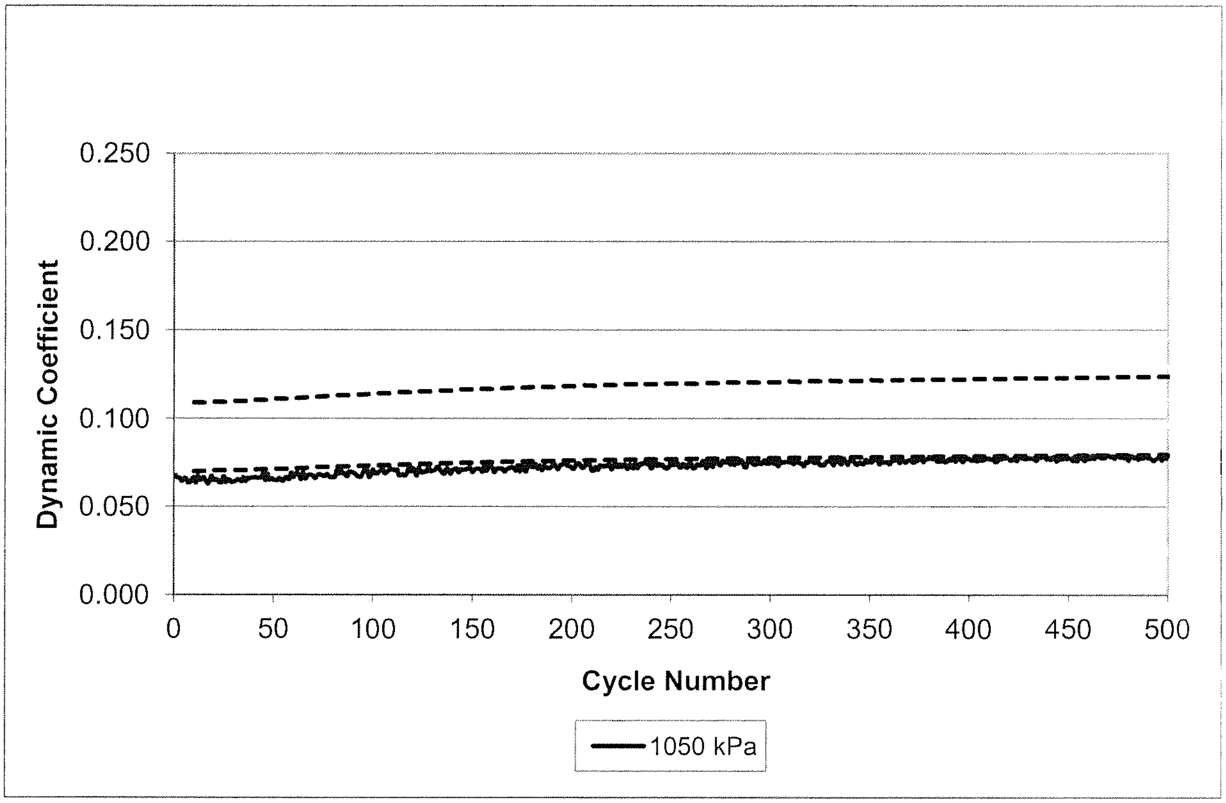
Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		F					
Dynamic Coefficient Vs. Load:		F					
Dynamic Coefficient Vs. Speed:		F					
Energy Limit:		P					
Static Coefficient Vs. Load:		P					
Static Coefficient Vs. Speed:		P					
Energy Limit:		P					
Total Wear:		0.020					
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand using 2009 batch parts. The results are compared to TO-4 testing limits.

F = Fail
P = Pass
N/A = Not Applicable

Test name:	A-109-I
Test date:	2/11/2014
Test description:	
Oil type:	LO292039
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12
Run name & desc:	A-109-I
Run date:	2/11/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	1220
Remarks:	
Number of cylces run:	977
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	
Disc name & desc:	1Y0709
Material:	SINTERED BRONZE
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	007080C800012
Remarks:	
Plate Name & desc:	8E4095
Surface:	0.8
Miscellaneous:	
Batch Number:	007080C800012
Remarks:	
Report limit name:	R-004-I
Limit file generated:	8/22/2012
Report format name:	REP1220 - SINTERED BRONZE

Test: A-109-I
Run: A-109-I
Started on: 2/11/2014 at 07:29:39

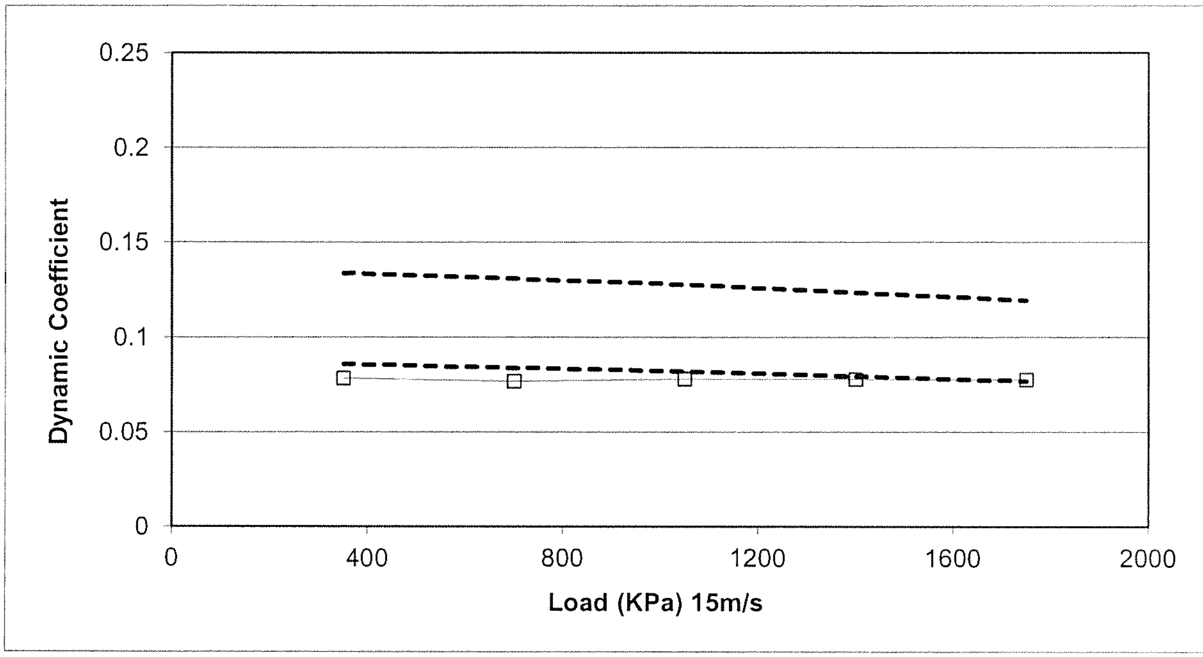


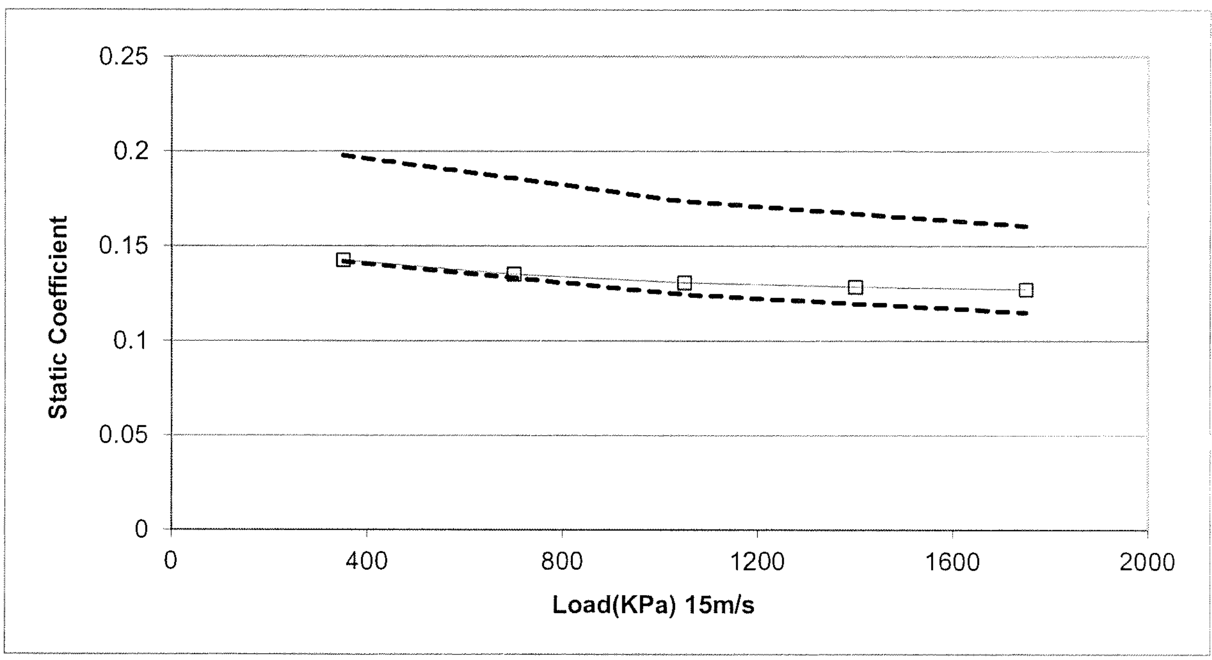
Wear Measurements
Thickness

Location	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
II	4.99	4.97	4.97	4.98	4.97	4.97
T	4.98	4.97	4.96	4.98	4.97	4.96
+	4.99	4.97	4.97	4.99	4.98	4.97
X	4.98	4.97	4.96	4.98	4.97	4.96
Y	4.99	4.99	4.97	4.99	4.99	4.97
Z	4.98	4.97	4.96	4.96	4.96	4.95
Average	4.99	4.97	4.97	4.98	4.97	4.96

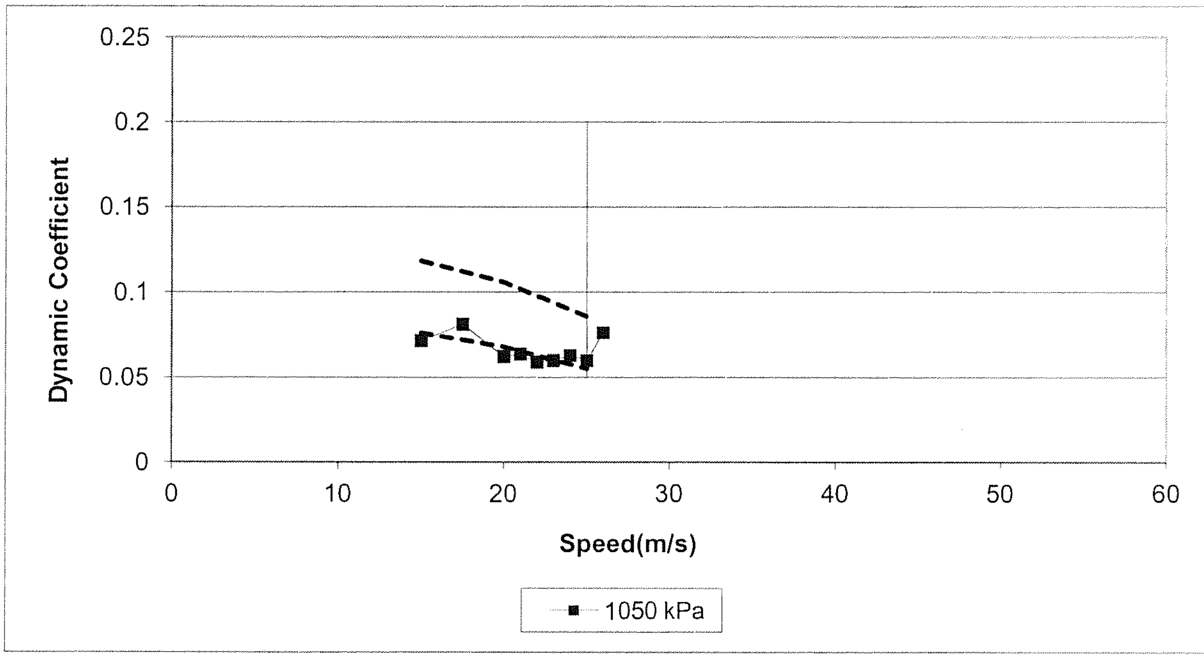
M1-M2 Compression set average wear: 0.012
M2-M3 average Wear: 0.008
Total Wear(all measurements in mm): 0.020

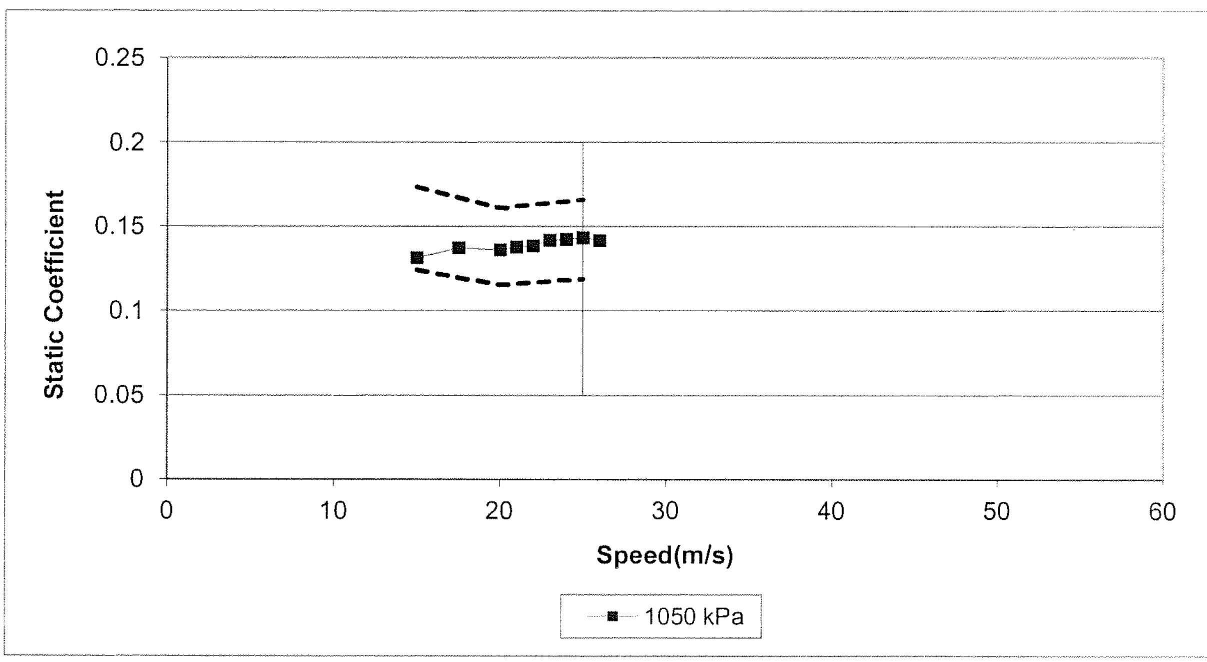
Test: A-109-I
Run: A-109-I
Started on: 2/11/2014 at 07:29:39



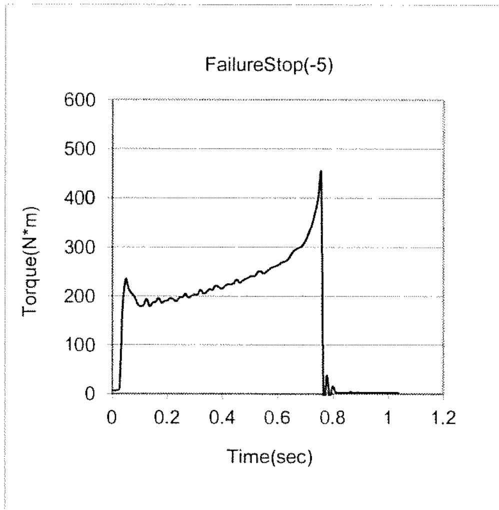


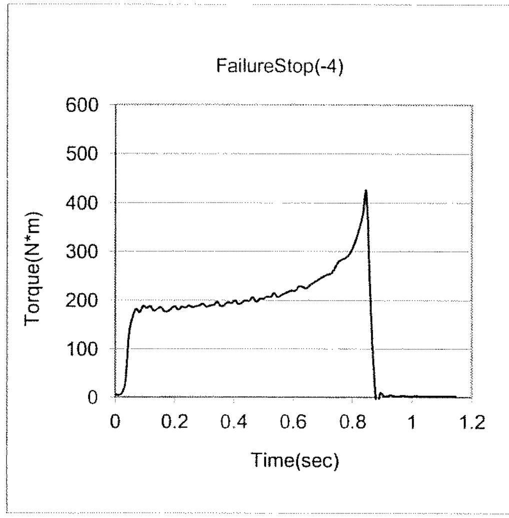
Test: A-109-I
Run: A-109-I
Started on: 2/11/2014 at 07:29:39

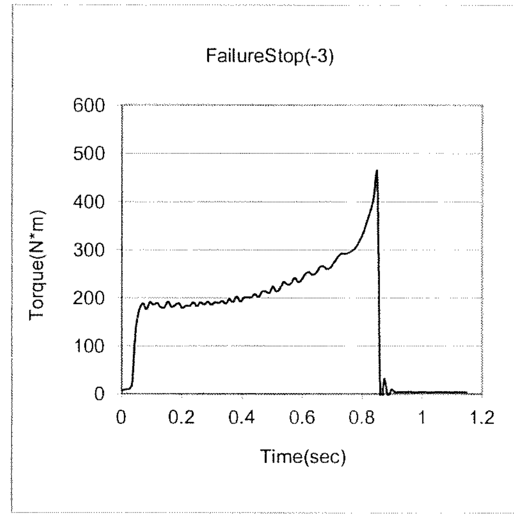


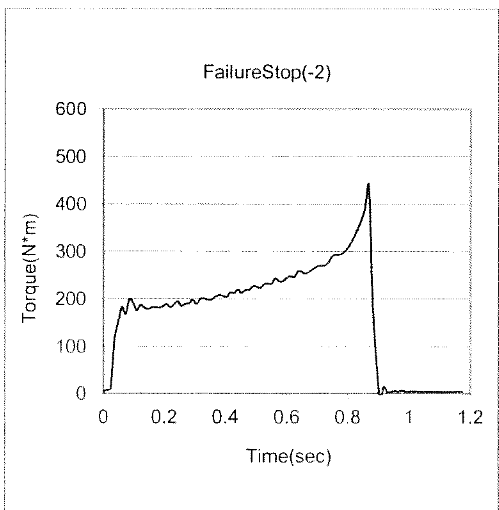


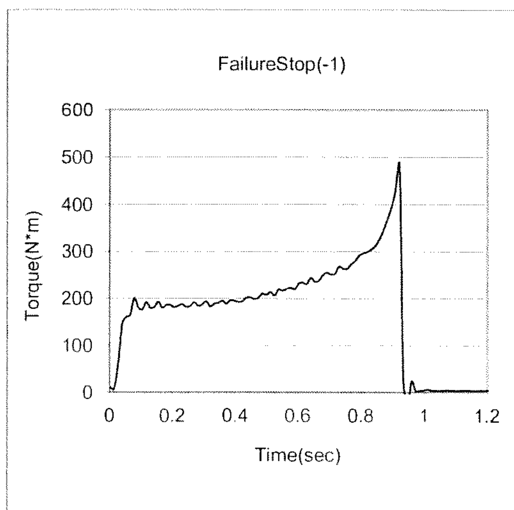
Test: A-109-I
Run: A-109-I
Started on: 2/11/2014 at 07:29:39

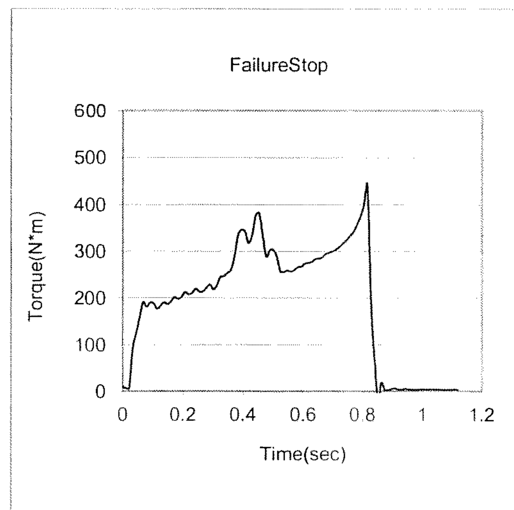












SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
SEQUENCE 1222 ONLY

Conducted for

ARMY LAB

Oil Code:
LO292039

Test Number:
A-110-I

February 12, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 2/12/2014
End of test date: 2/12/2014
Oil Code: LO292039

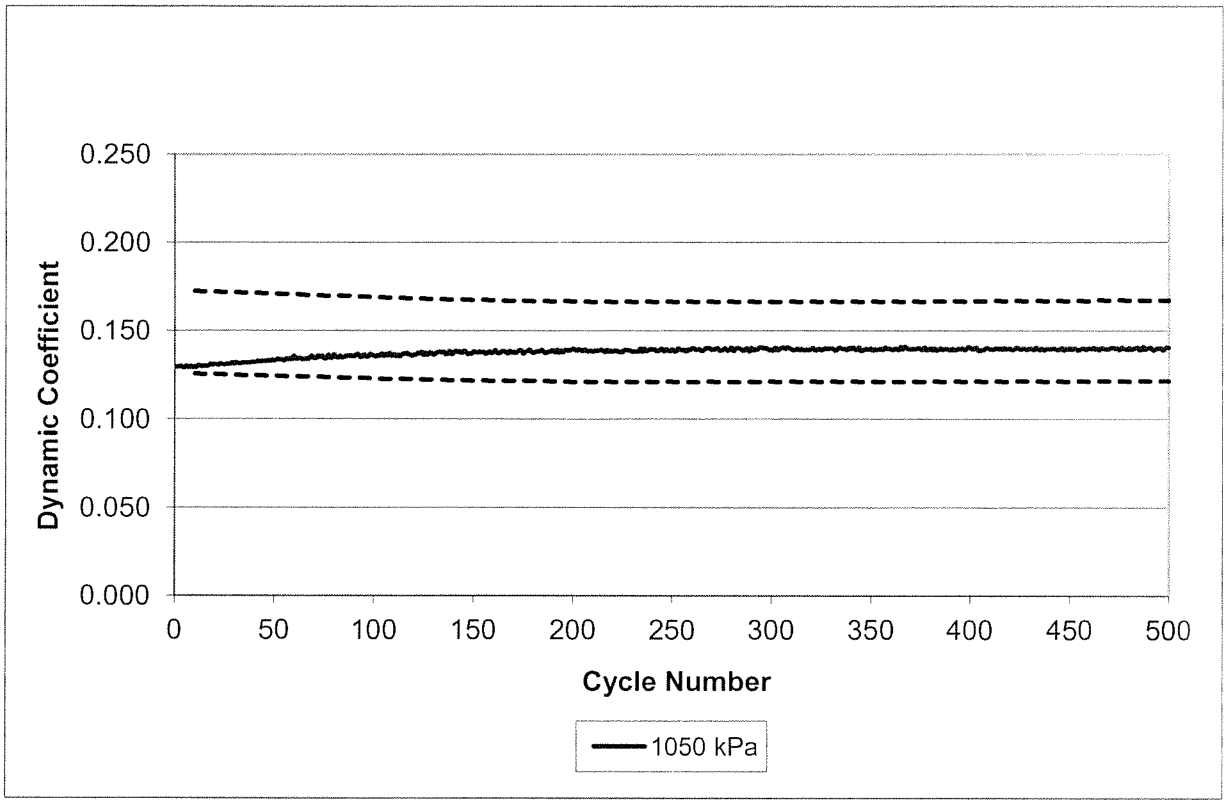
Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:				P			
Dynamic Coefficient Vs. Load:				P			
Dynamic Coefficient Vs. Speed:				P			
Energy Limit:				P			
Static Coefficient Vs. Load:				P			
Static Coefficient Vs. Speed:				P			
Energy Limit:				P			
Total Wear:				0.033			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand using 2009 batch parts.
The results are compared to TO-4 testing limits.

F = Fail
P = Pass
N/A = Not Applicable

Test name:	A-110-I
Test date:	2/12/2014
Test description:	
Oil type:	LO292039
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12
Run name & desc:	A-110-I
Run date:	2/12/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	1222
Remarks:	
Number of cylces run:	1072
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	
Disc name & desc:	1Y0711
Material:	WHEEL BRAKE PAPER
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	06MR928188
Remarks:	
Plate Name & desc:	1Y0726
Surface:	0.27
Miscellaneous:	
Batch Number:	06MR928188
Remarks:	
Report limit name:	R-005-I
Limit file generated:	8/24/2012
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-110-I
Run: A-110-I
Started on: 2/12/2014 at 07:35:35

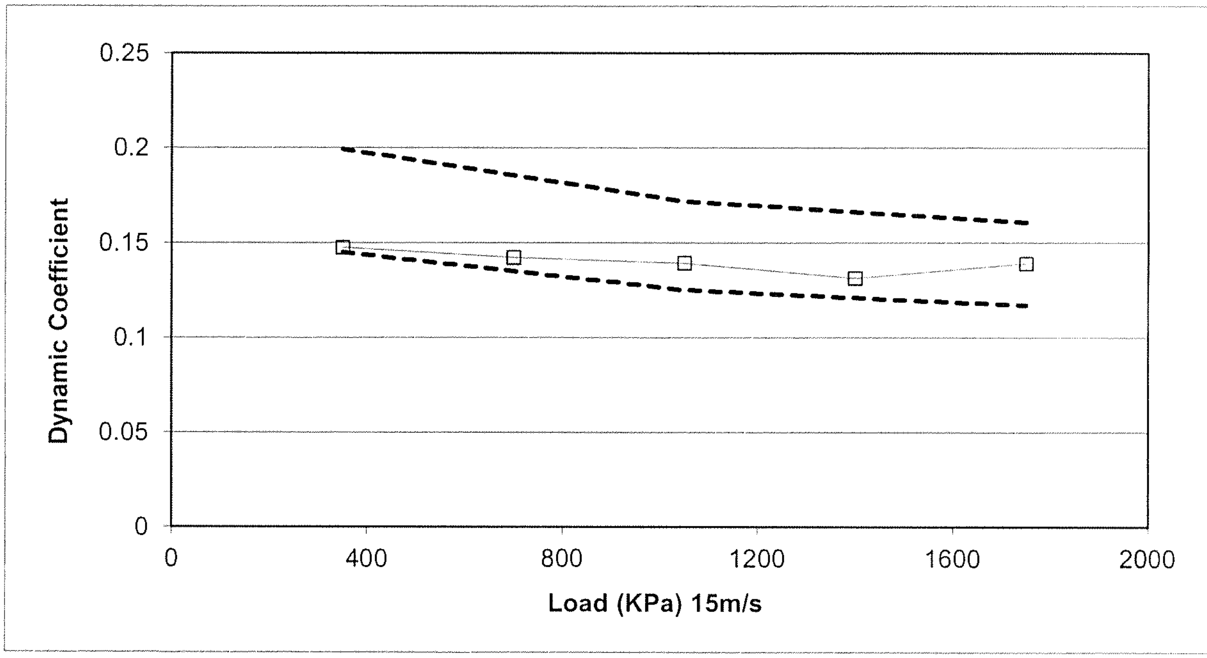


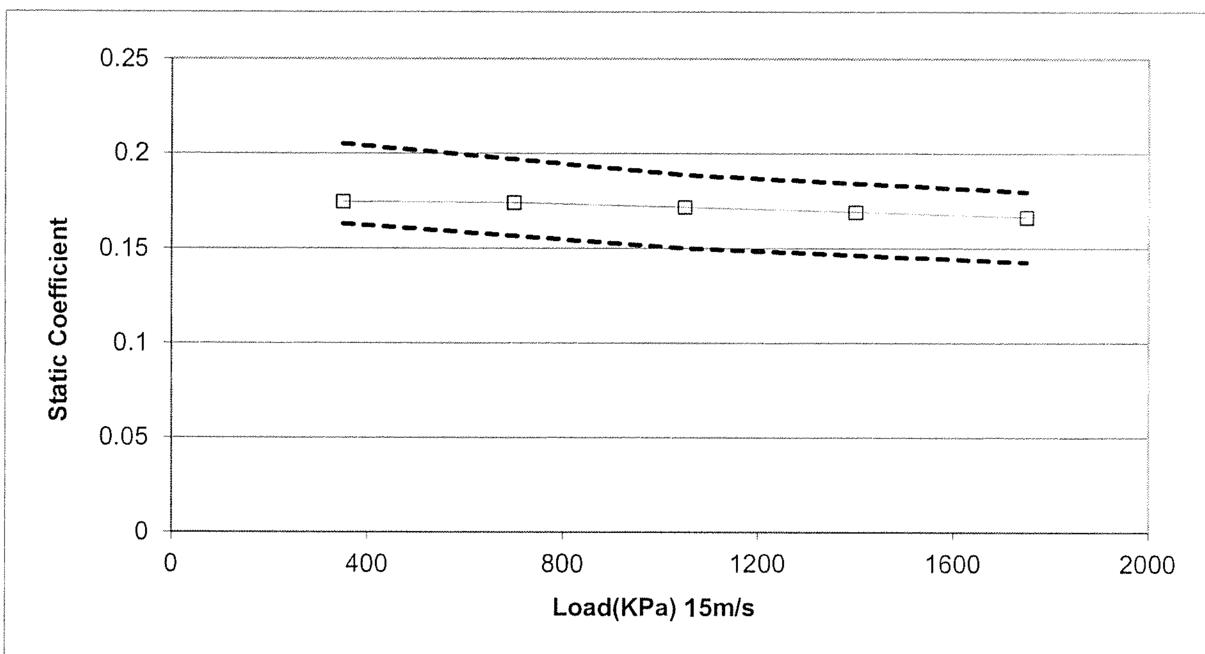
Wear Measurements
Thickness

Location	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
II	5.00	4.97	4.96	4.99	4.96	4.96
T	4.99	4.96	4.96	4.99	4.96	4.95
+	4.97	4.95	4.94	4.97	4.95	4.94
X	4.98	4.95	4.94	4.97	4.94	4.94
Y	4.99	4.96	4.96	4.99	4.96	4.96
Z	4.99	4.96	4.96	4.99	4.96	4.96
Average	4.99	4.96	4.95	4.98	4.95	4.95

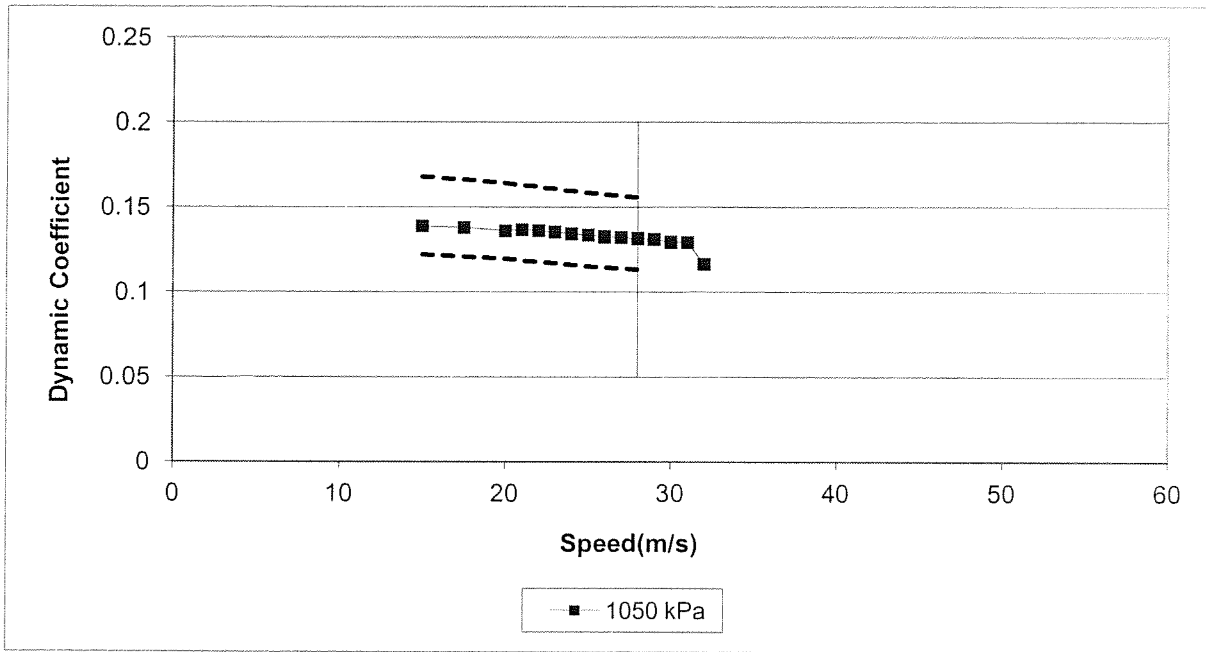
M1-M2 Compression set average wear:	0.028
M2-M3 average Wear:	0.005
Total Wear(all measurements in mm):	0.033

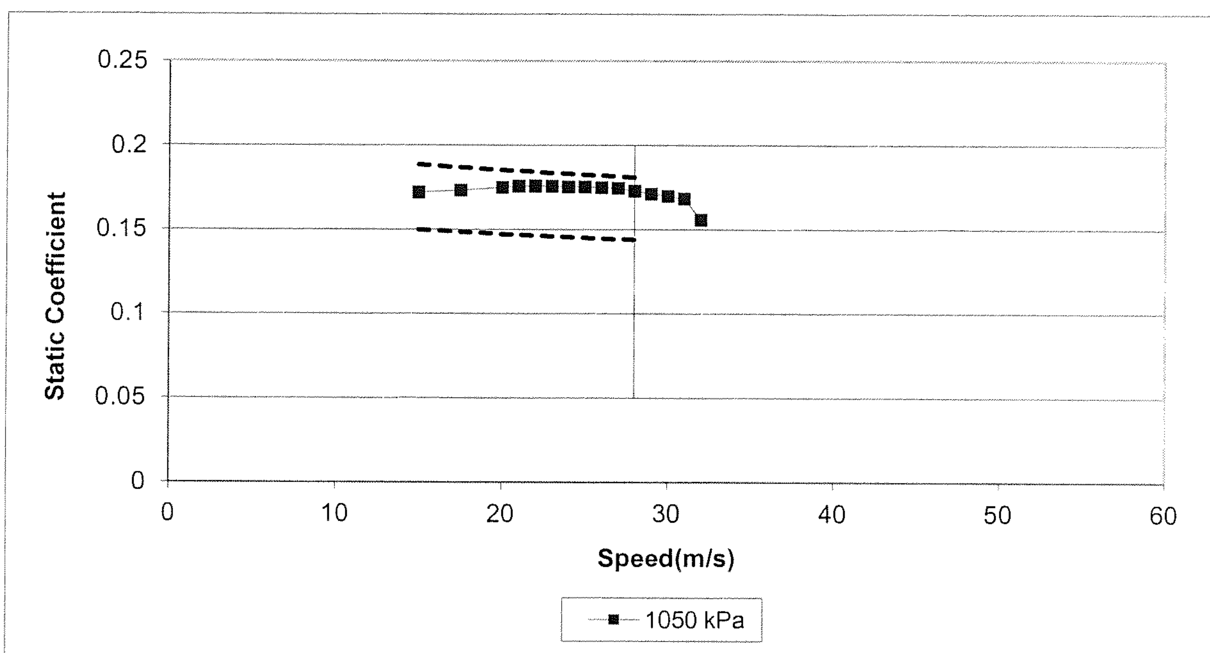
Test: A-110-I
Run: A-110-I
Started on: 2/12/2014 at 07:35:35



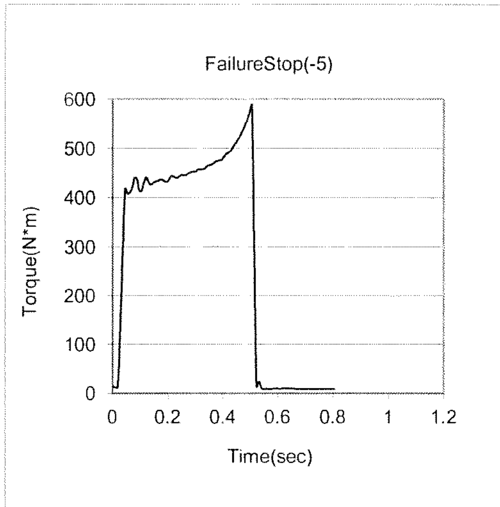


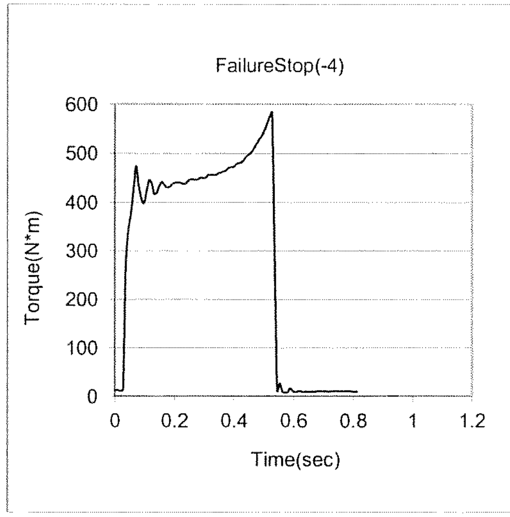
Test: A-110-I
Run: A-110-I
Started on: 2/12/2014 at 07:35:35

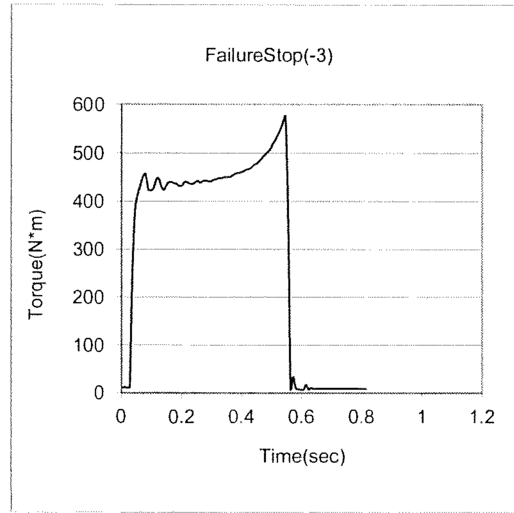


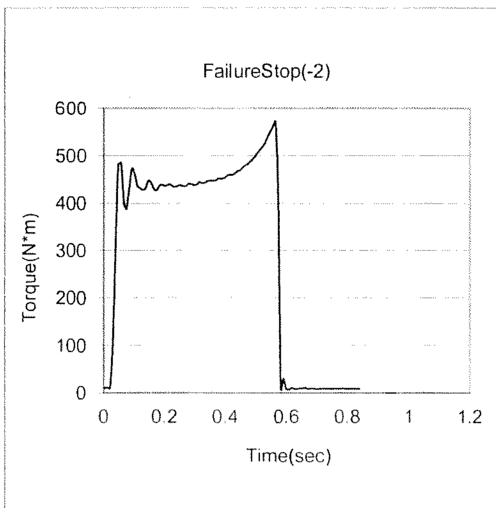


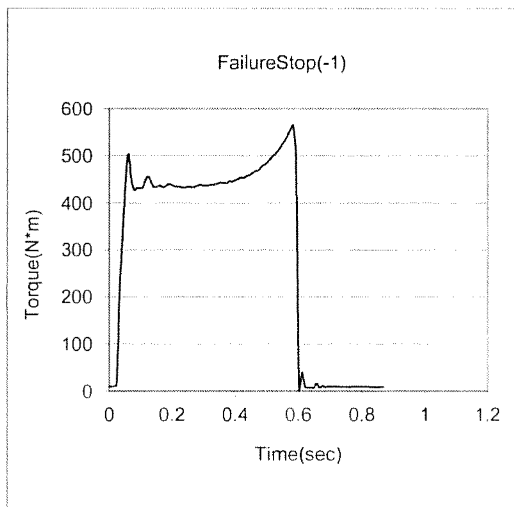
Test: A-110-I
Run: A-110-I
Started on: 2/12/2014 at 07:35:35

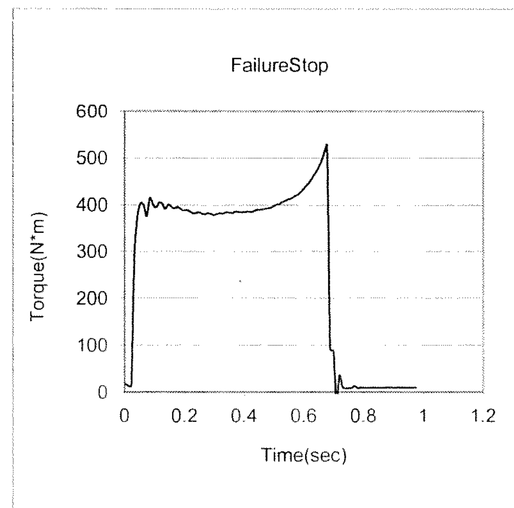












SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
FRRET SEQUENCE ONLY

Conducted for

ARMY LAB

Oil Code:
LO292039

Test Number:
A-111-I

February 18, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 2/14/2014
End of test date: 2/18/2014
Oil Code: LO292039

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:							F
Dynamic Coefficient Vs. Load:							
Dynamic Coefficient Vs. Speed:							
Energy Limit:							
Static Coefficient Vs. Load:							
Static Coefficient Vs. Speed:							
Energy Limit:							
Total Wear:							
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

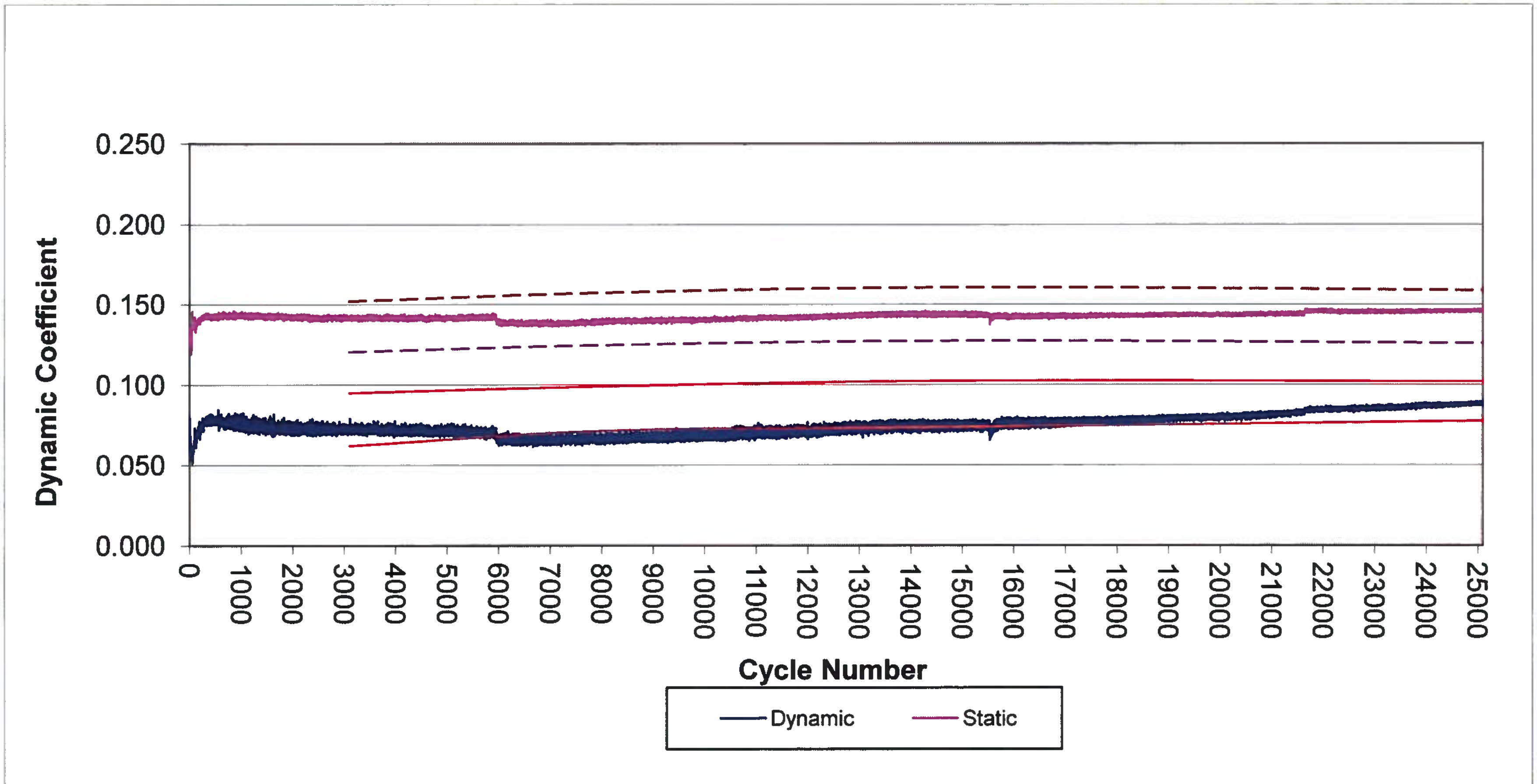
Comments: This testing was conducted on a referenced test stand using 2009 batch parts. The results are compared to TO-4 testing limits.

This test is a fail because a small amount of dynamic data was below the lower limit line.

F = Fail
P = Pass
N/A = Not Applicable

Test name:	A-111-I
Test date:	2/13/2014
Test description:	
Oil type:	LO292039
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12
Run name & desc:	A-111-I
Run date:	2/13/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	FRRET
Remarks:	
Number of cylces run:	25100
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	
Disc name & desc:	1Y0709
Material:	SINTERED BRONZE
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	0071380C00012
Remarks:	
Plate Name & desc:	1Y0726
Surface:	0.29
Miscellaneous:	
Batch Number:	0071380C00012
Remarks:	
Report limit name:	R-008-I
Limit file generated:	9/14/2012
Report format name:	REPFRRET - FRICTION RETENTION

Test: A-111-I
Run: A-111-I
Started on: 02/13/2014 at 09:39:03



SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON TRANSMISSION FLUID
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted on

Oil Code:
LO-306520

Test Number:
C4-8-1459

March 10, 2014

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

VIII. Graphite Clutch Friction Test

Test Laboratory: SWRI
Test Number: C4-8-1459
Friction Plate Batch: LOT 45
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-306520
Sponsor Fluid Code: LO306520
Completion Date: 03/10/14

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0850	0.0672

	Before	After
Pack Clearance	0.4826	0.5588

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1428	10/16/13	MIL-PRF-2104H
C4-0-1429	10/18/13	MIL-PRF-2104H
C4-0-1440	01/04/14	MIL-PRF-2104H

	New	EOT
Viscosity at 40°C, cSt	47.47	42.24
Viscosity at 100°C, cSt	8.88	7.71
Iron Content, ppm	2	35

D5185	New Fluid (ppm)
Ba	<1
B	<1
Ca	3586
Mg	10
P	1397
Si	6
Na	24
Zn	1671

Name: Matthew Jackson
Title: Manager

Signature:
Date: 3/19/14

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO306520**	Test Number: **C4-8-1459**
Lab Fluid Code: **LO-306520**	Fric. Plate Batch: **LOT 45**
Completion Date: **3/10/2014**	Steel Plate Batch: **10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.11	54	63	47	16	74	61
1000	1.14	53	61	44	17	67	60

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.71	112	129	108	21	160	130
2000	0.74	109	123	104	19	169	127
2500	0.77	104	118	100	18	135	125
3500	0.81	100	115	91	24	138	124
4000	0.83	98	115	88	27	135	121
4500	0.84	95	112	86	26	137	121
5000	0.85	96	112	83	29	131	122
5500	0.86	95	110	78	32	131	121

	Limits		Results		
	Min	Max	1,500 N	5,500 N	% Change
Slip Time Max.	N/A	N/A	0.71	0.86	21.13
0.2 Second Dynamic Coeff.	N/A	N/A	0.101	0.073	-27.723
Mid-Point Fric. Coeff. Min.	N/A	N/A	0.105	0.089	-15.238
Static Friction Coeff.	N/A	N/A	0.121	0.103	-14.876
Low Speed Peak Fric. Coeff.	N/A	N/A	0.150	0.123	-18.000
0.25 Second Low Speed Coeff.	N/A	N/A	0.122	0.113	-7.377

The Allison TES-228 (C4) specification is obsolete. Batch 45 limits apply only to tests conducted for Allison TES-439 and TES-295 specifications.

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO306520 **Test Number : C4-8-1459** **Completion Date : 3/10/2014**

Lab Fluid Code : LO-306520 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 45**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2150	2.1560	2.2190	2.1340	0.0590		0.0850
	120	2.2180	2.1680	2.2230	2.1470	0.0500		0.0760
	240	2.2220	2.1680	2.2170	2.1380	0.0540		0.0790
	Average					0.0543	0.0672	0.0800
STEEL SEPARATORS								
1	Top	1.7560	1.7560	1.7550	1.7550	0.0000		0.0000
	120	1.7550	1.7550	1.7550	1.7550	0.0000		0.0000
	240	1.7550	1.7550	1.7560	1.7560	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	120	1.7480	1.7480	1.7470	1.7470	0.0000		0.0000
	240	1.7480	1.7480	1.7480	1.7480	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T. PLATES IN GOOD CONDITION

(Anything Unusual)

Test Date: 3/10/2014

Operator's Name: JGUERRERO

Reviewed By (Signature and Date)

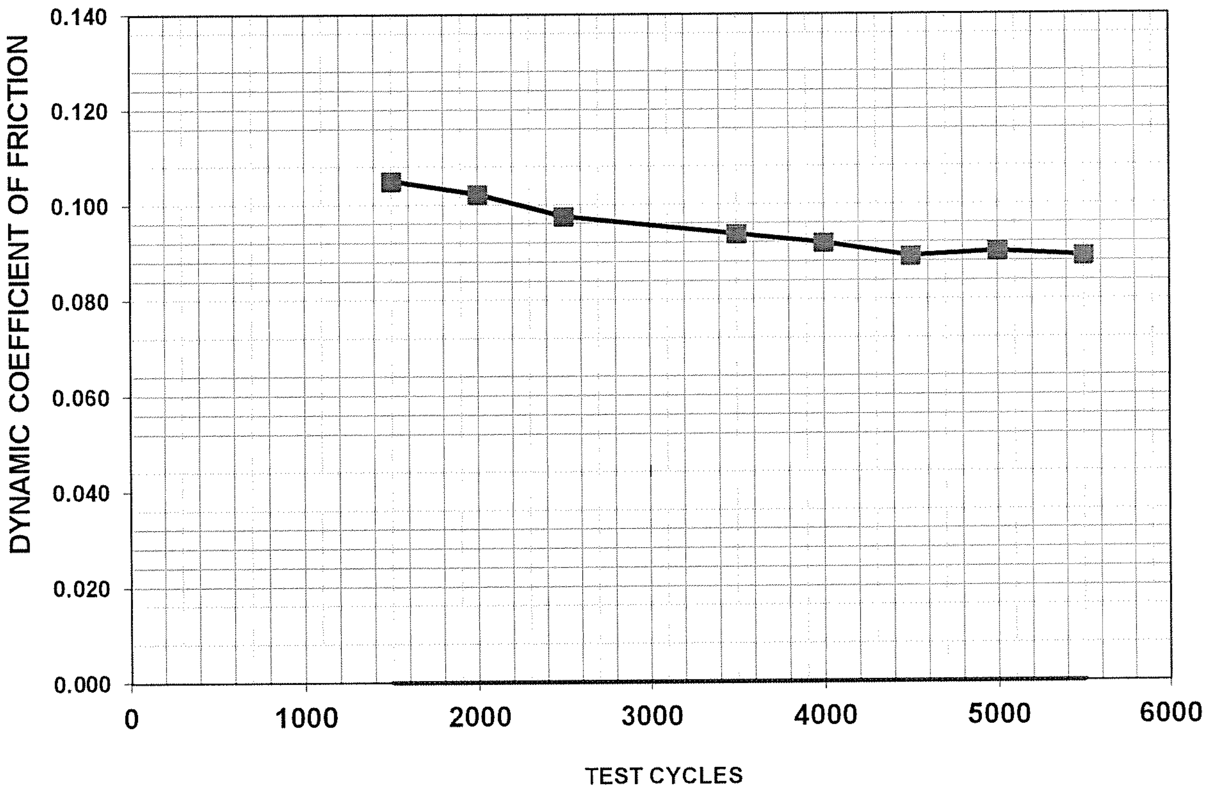
3/19/14

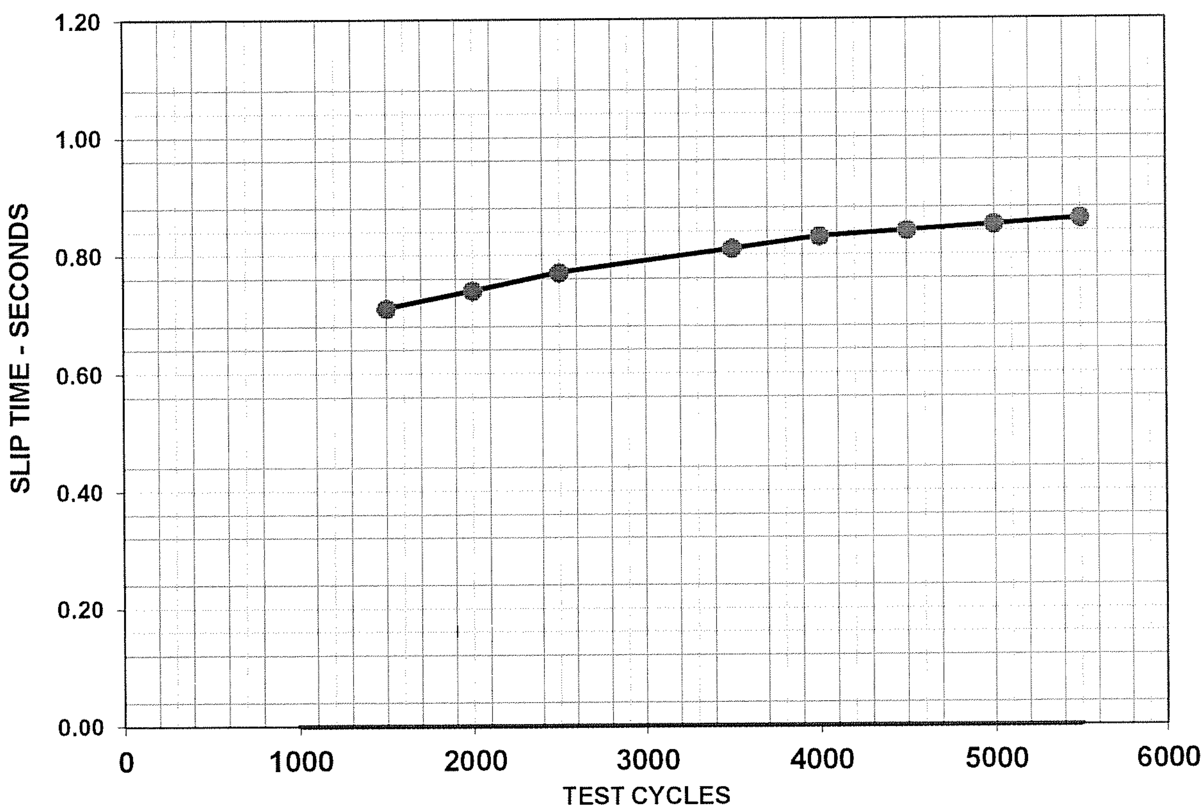
Pack ID#: 5159

ALLISON TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 3/10/2014
Test Number: C4-8-1459

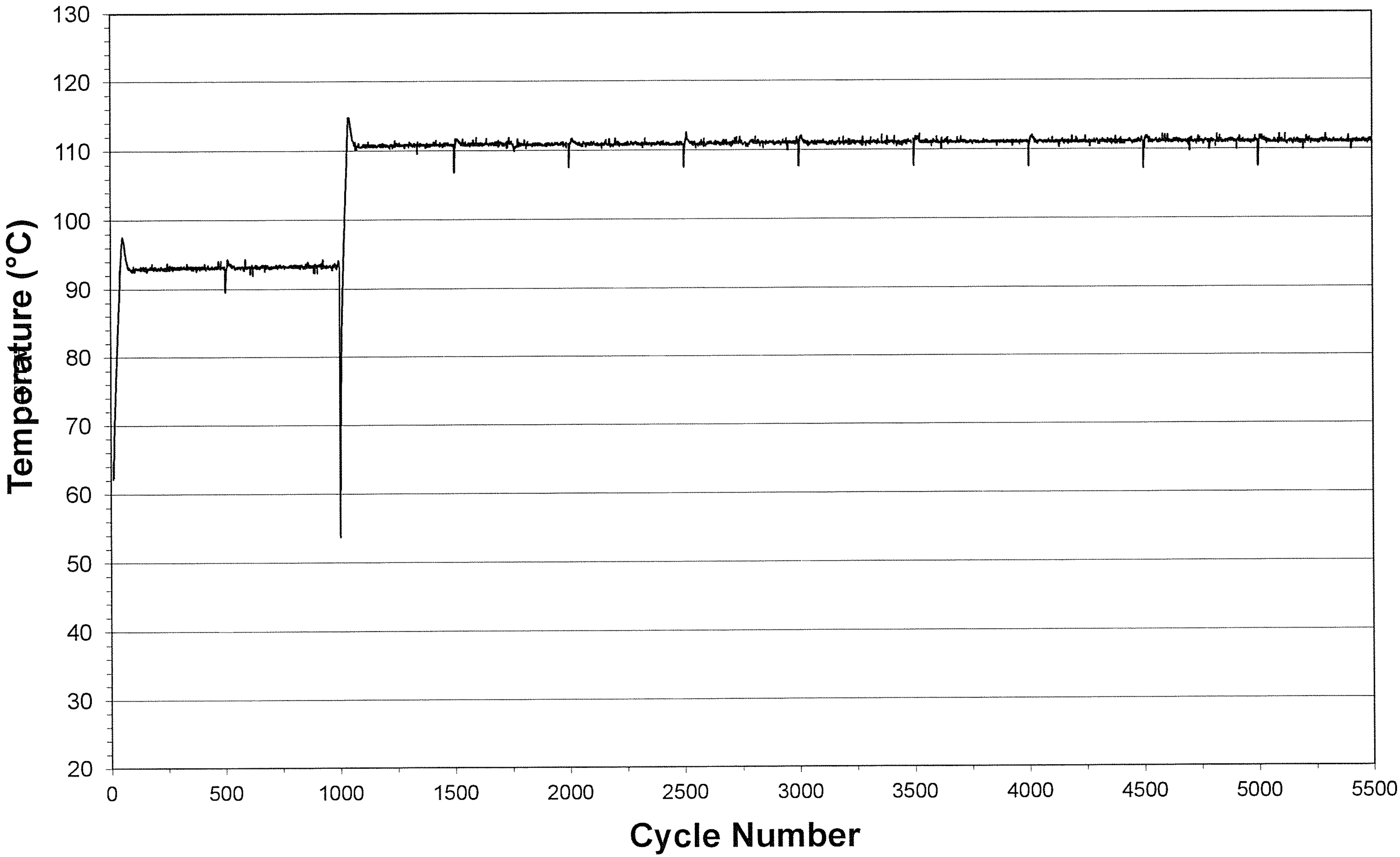
Fluid Code: LO306520
Plate Batch: LOT 45
Steel Batch: 10/9/2008





C4-8-1459 LO306520

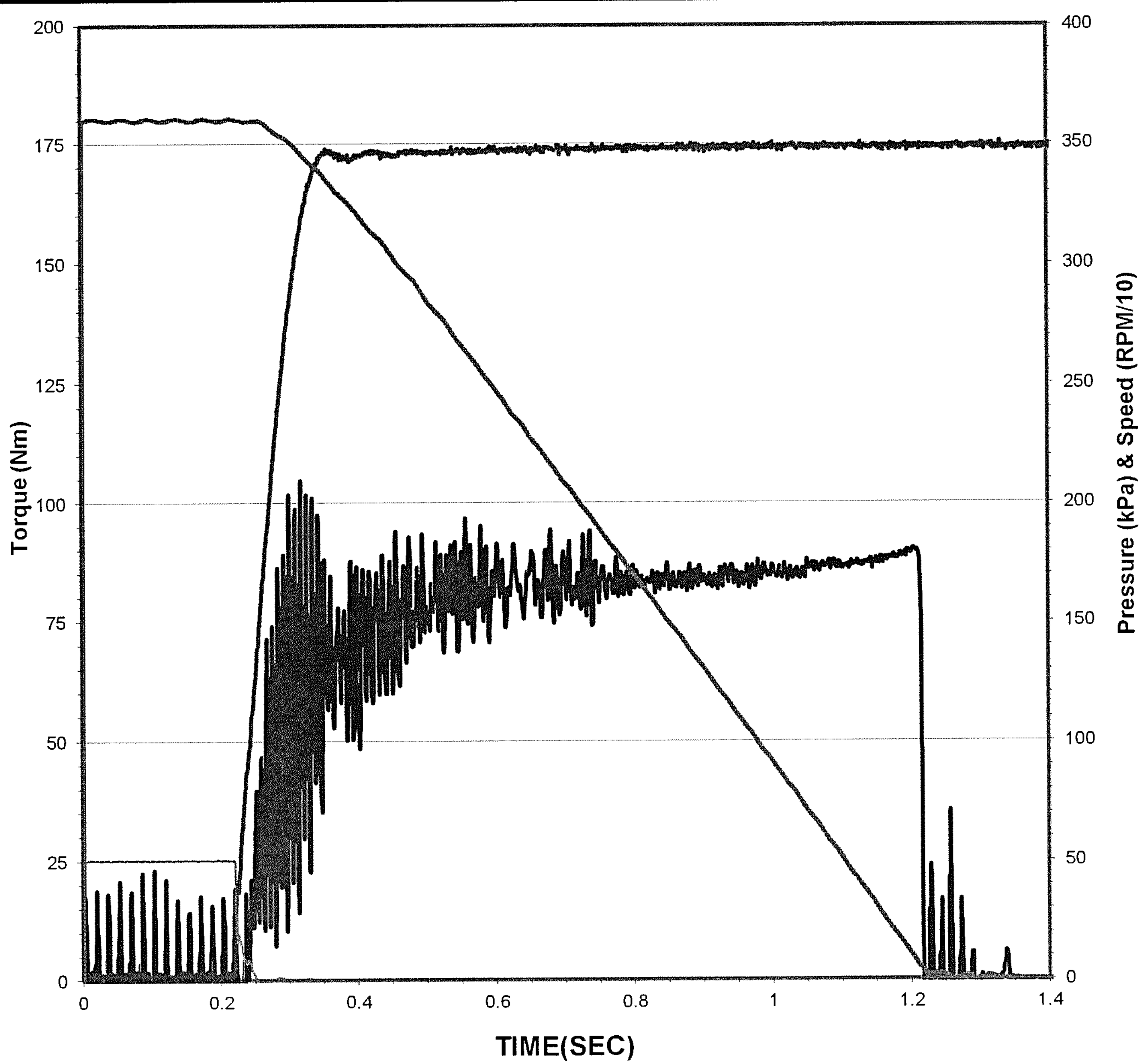
AVG: Phase A = 92.5 °C, Phase B = 110.9 °C



DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	19:33:22
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	10
Temperature:	64.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	346 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	0.996 Sec

Torque

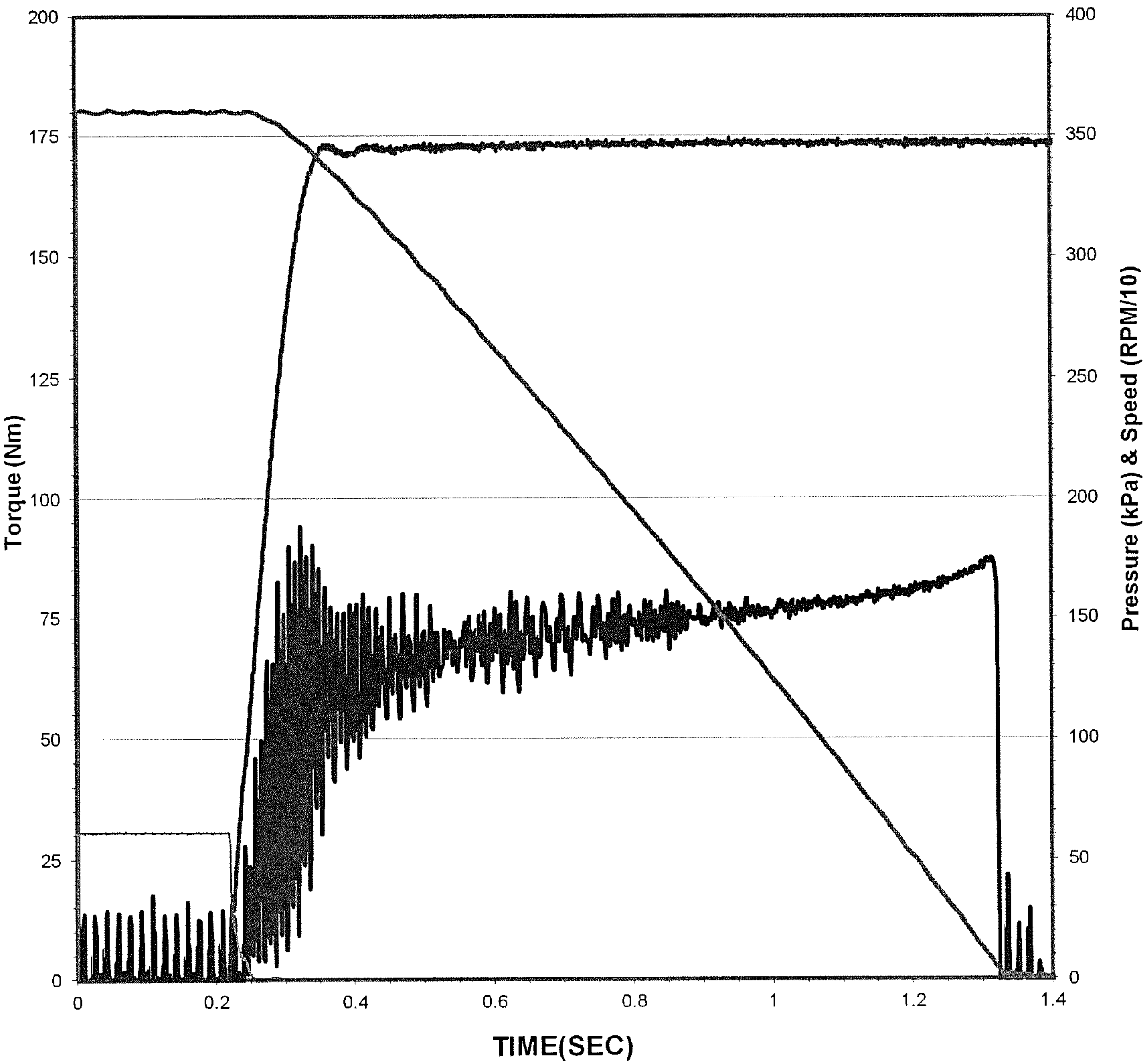
0.2 Sec Dyn:	75 N*m
Midpoint Dyn:	84 N*m
LwSpd Dynamic:	89 N*m

Coefficient of Friction

.2 Sec Dyn:	0.124
Midpoint Dyn:	0.140
LwSpd Dynamic:	0.148

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	21:35:48
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	499
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.1 Sec

Torque

0.2 Sec Dyn:	65 N*m
Midpoint Dyn:	74 N*m
LwSpd Dynamic:	86 N*m

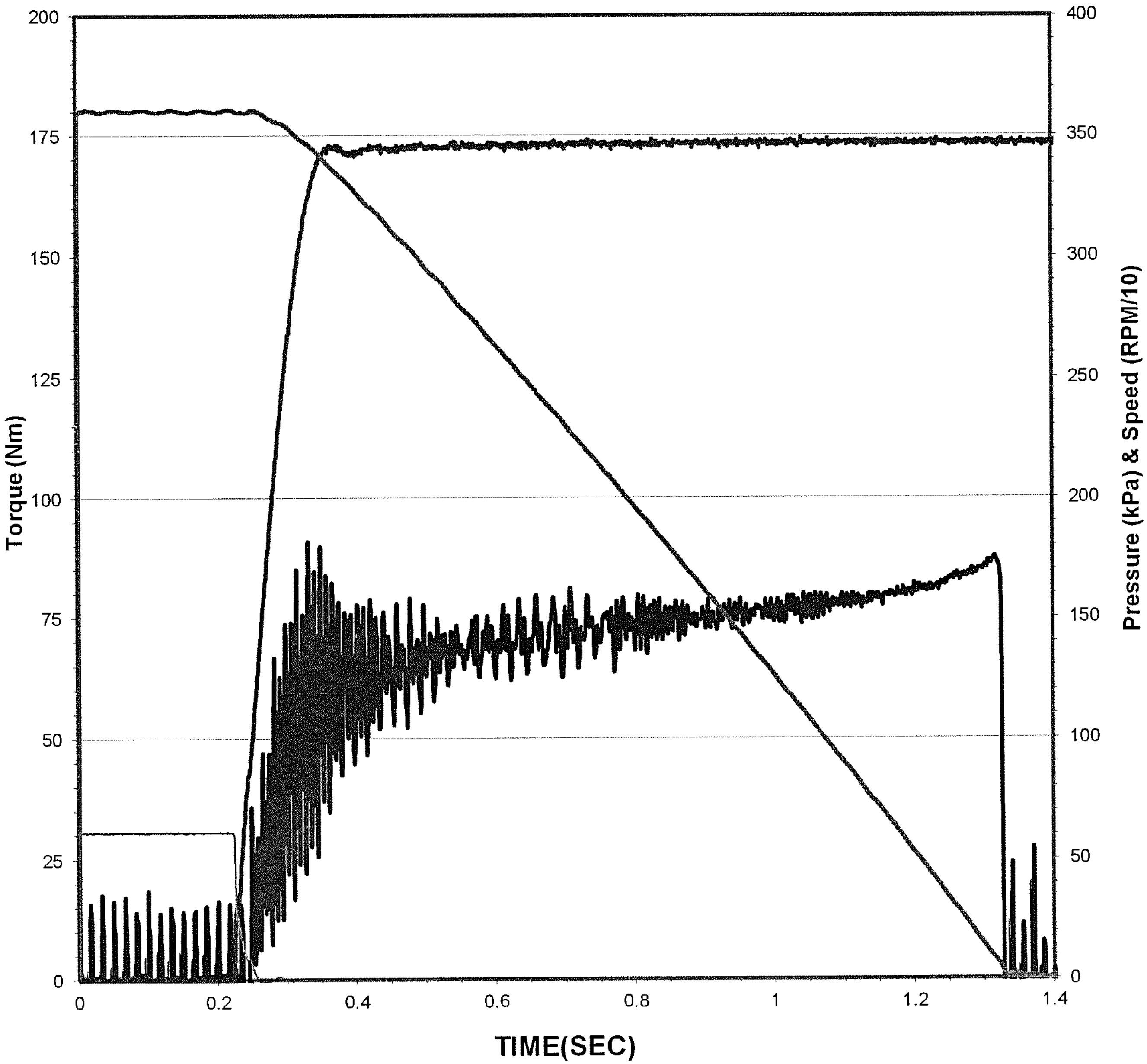
Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.123
LwSpd Dynamic:	0.143

A-122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	21:36:04
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	500
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.1 Sec

Torque

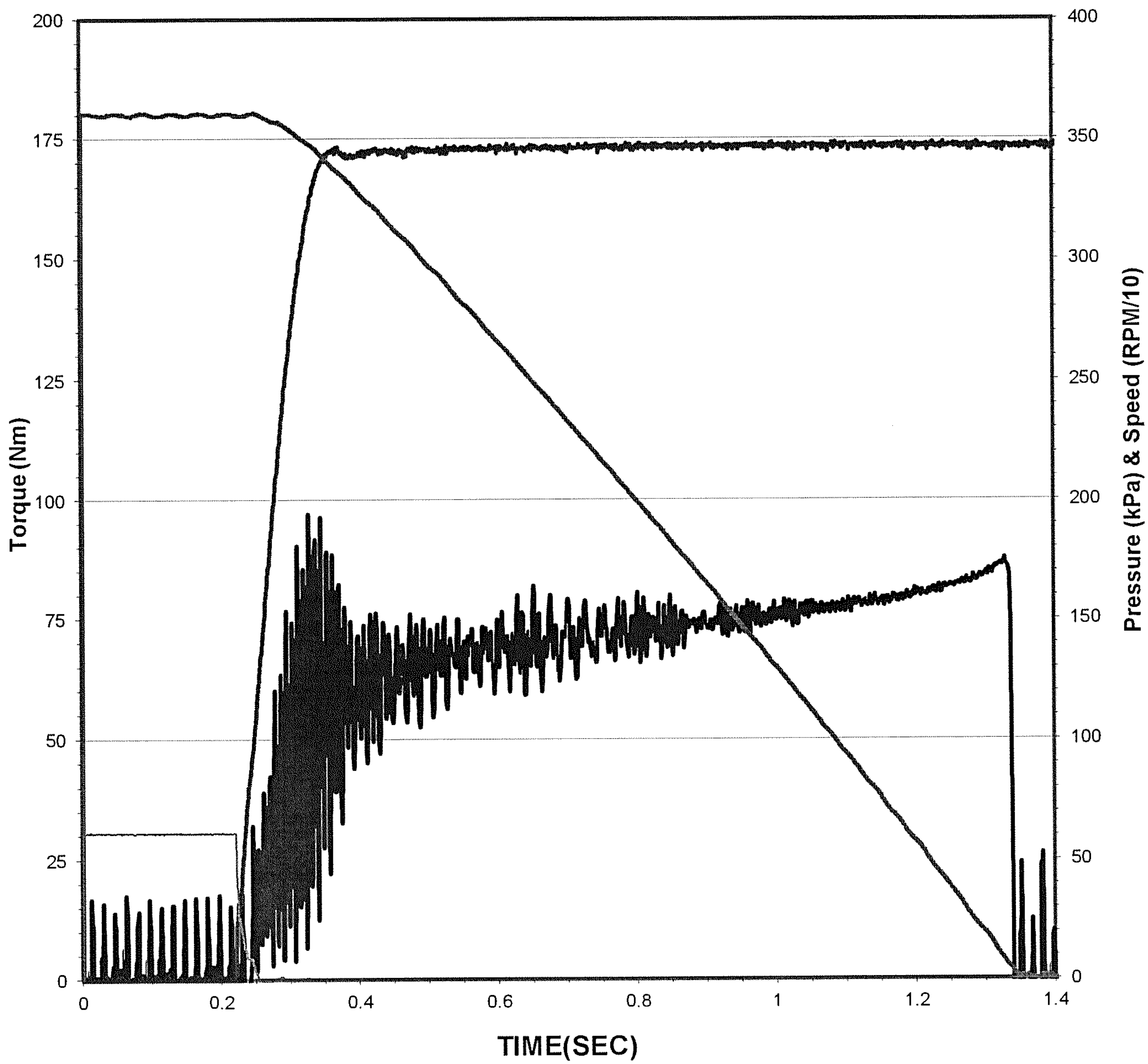
0.2 Sec Dyn:	64 N*m
Midpoint Dyn:	74 N*m
LwSpd Dynamic:	84 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.124
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	21:36:30
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	501
Temperature:	89.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.116 Sec

Torque

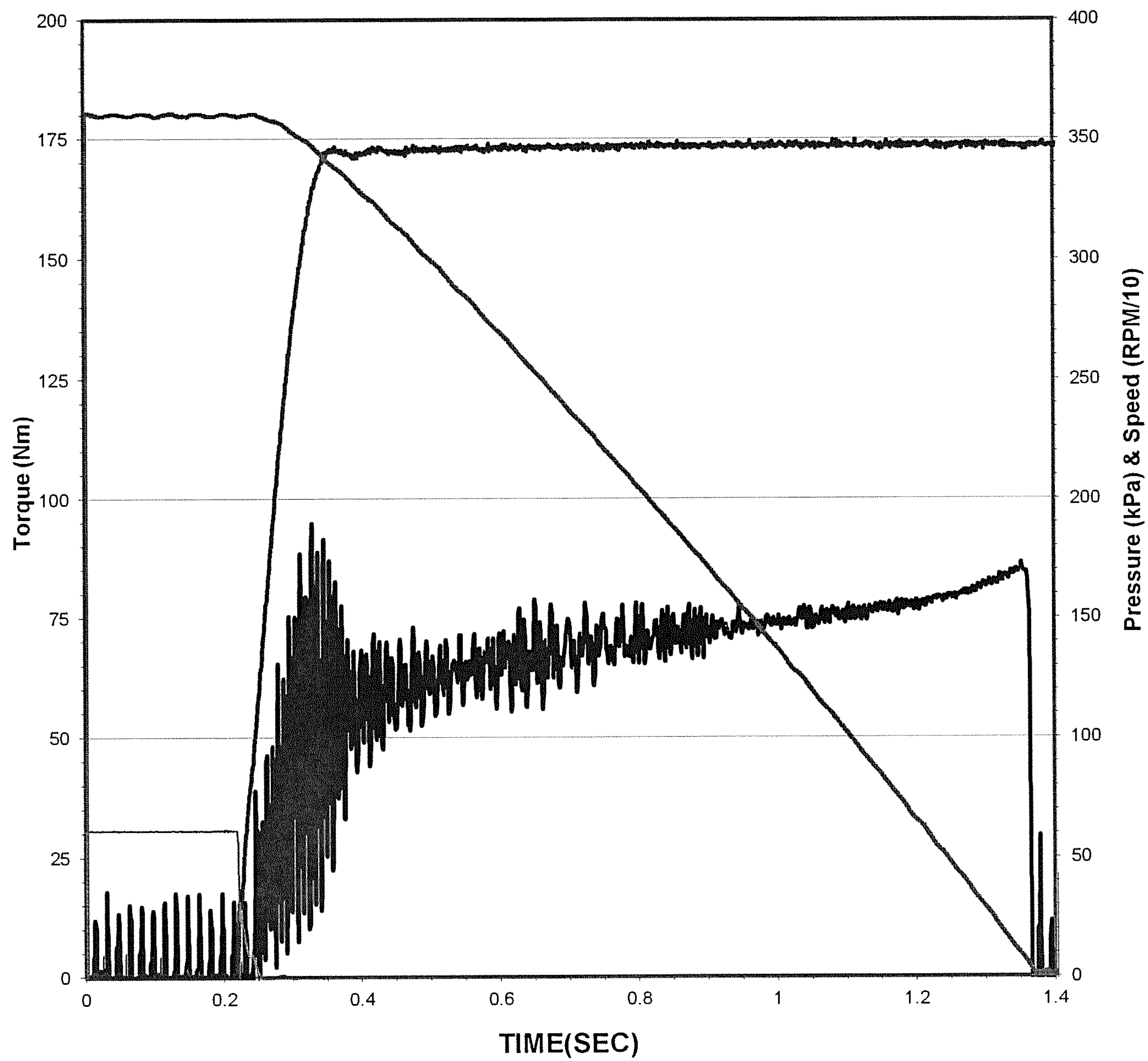
0.2 Sec Dyn:	62 N*m
Midpoint Dyn:	73 N*m
LwSpd Dynamic:	86 N*m

Coefficient of Friction

.2 Sec Dyn:	0.104
Midpoint Dyn:	0.121
LwSpd Dynamic:	0.142

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	23:40:45
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	998
Temperature:	93.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.142 Sec

Torque

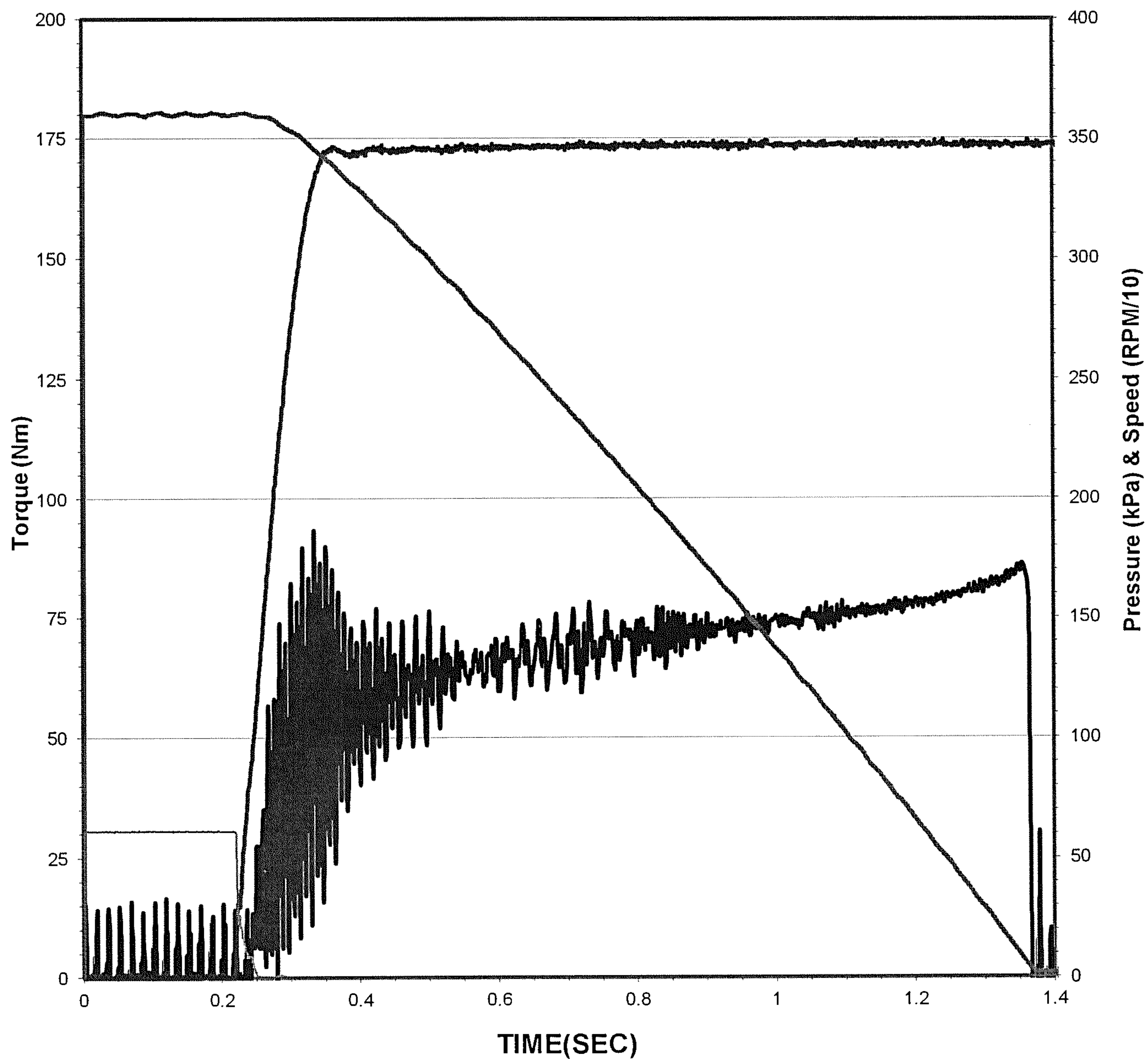
0.2 Sec Dyn:	60 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	84 N*m

Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.139

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	23:41:00
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	999
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.142 Sec

Torque

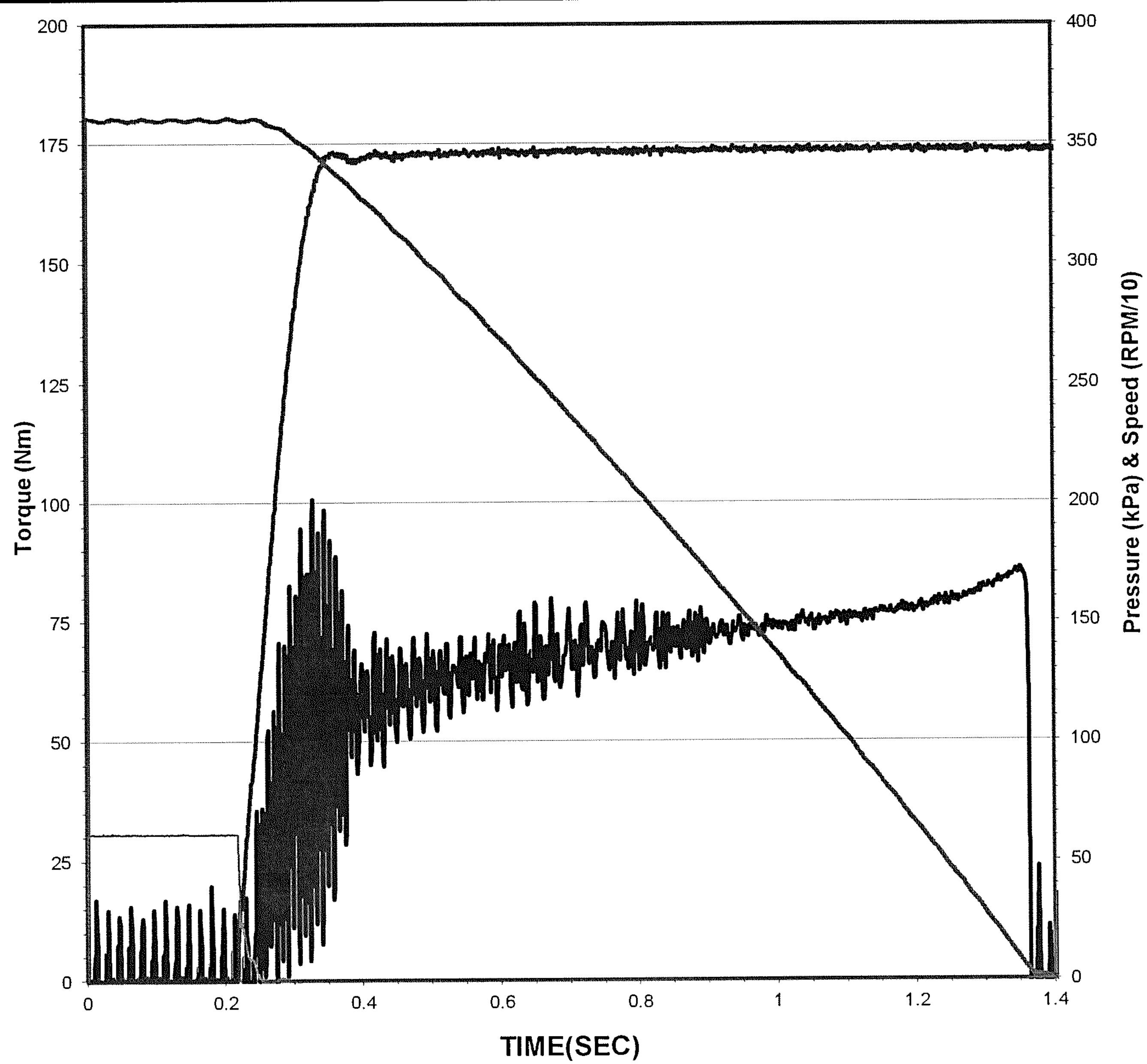
0.2 Sec Dyn:	60 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	83 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.138

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	3/9/2014
Time of Test:	23:41:15
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1000
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.145 Sec

Torque

0.2 Sec Dyn:	61 N*m
Midpoint Dyn:	72 N*m
LwSpd Dynamic:	82 N*m

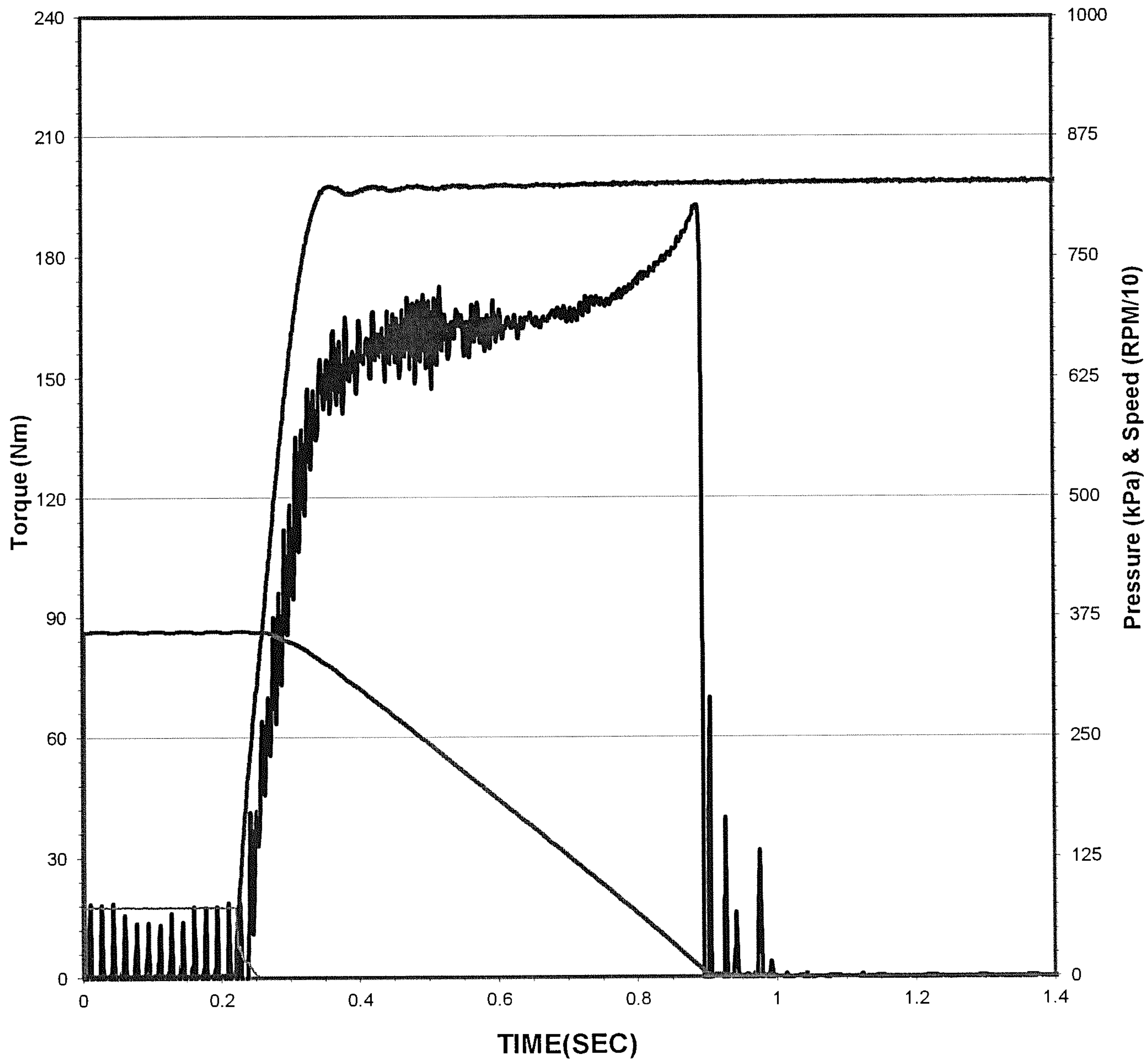
Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.136

A-127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	0:08:09
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1010
Temperature:	84.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	821 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.675 Sec

Torque

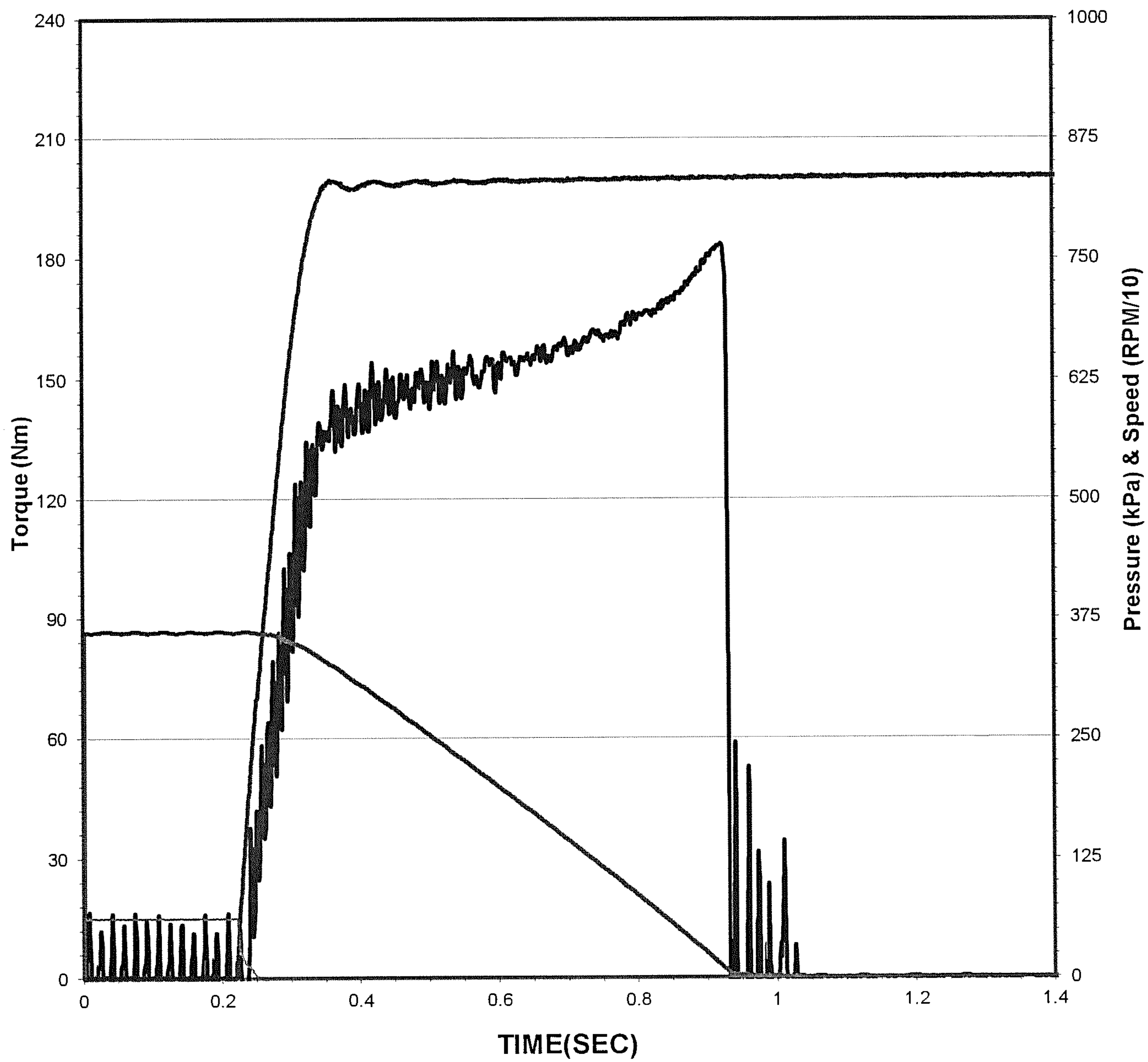
0.2 Sec Dyn:	159 N*m
Midpoint Dyn:	163 N*m
LwSpd Dynamic:	189 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	2:10:24
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1499
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.71 Sec

Torque

0.2 Sec Dyn:	147 N*m
Midpoint Dyn:	153 N*m
LwSpd Dynamic:	178 N*m

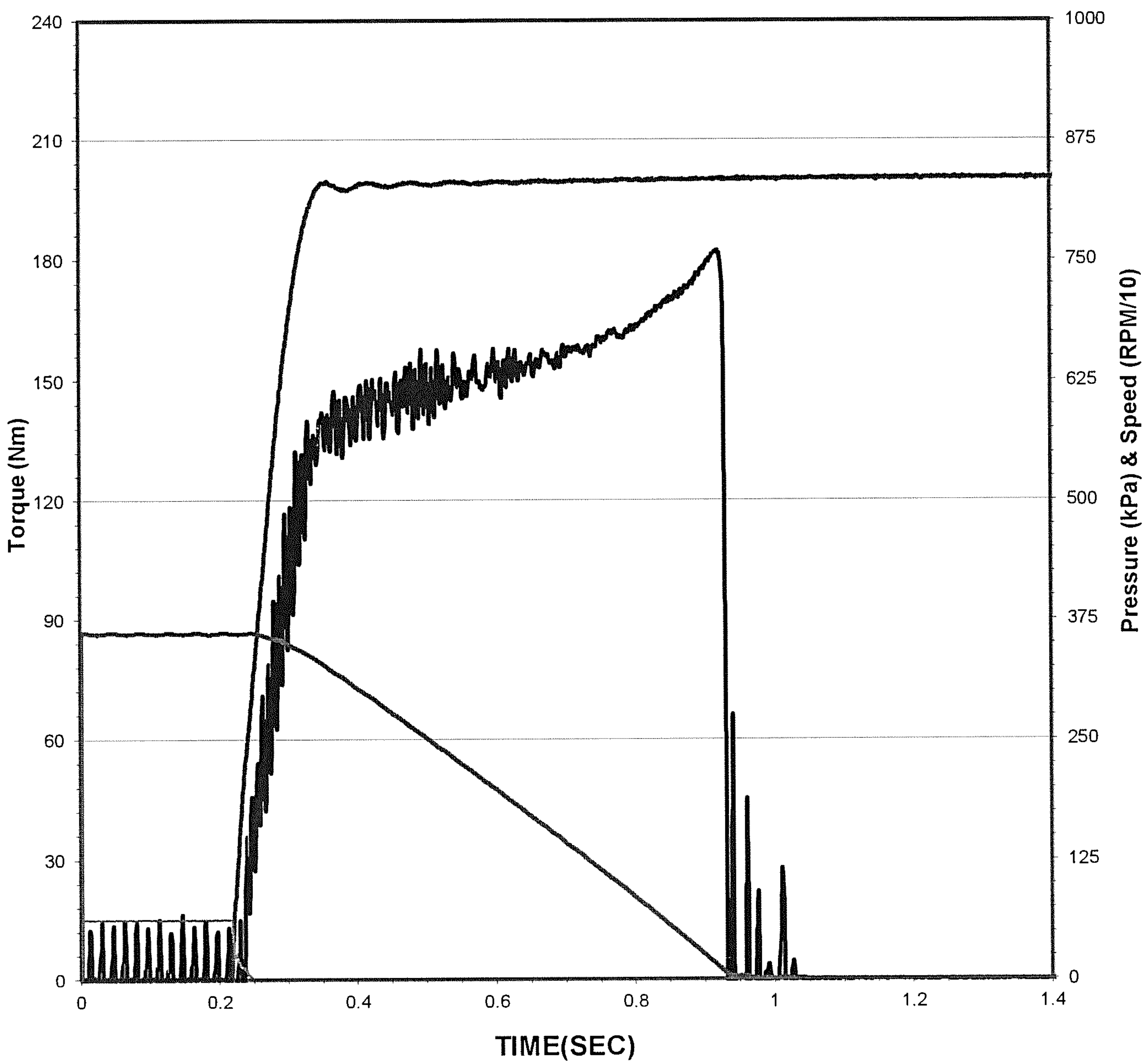
Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.106
LwSpd Dynamic:	0.123

A-129

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	2:10:39
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1500
Temperature:	110.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.714 Sec

Torque

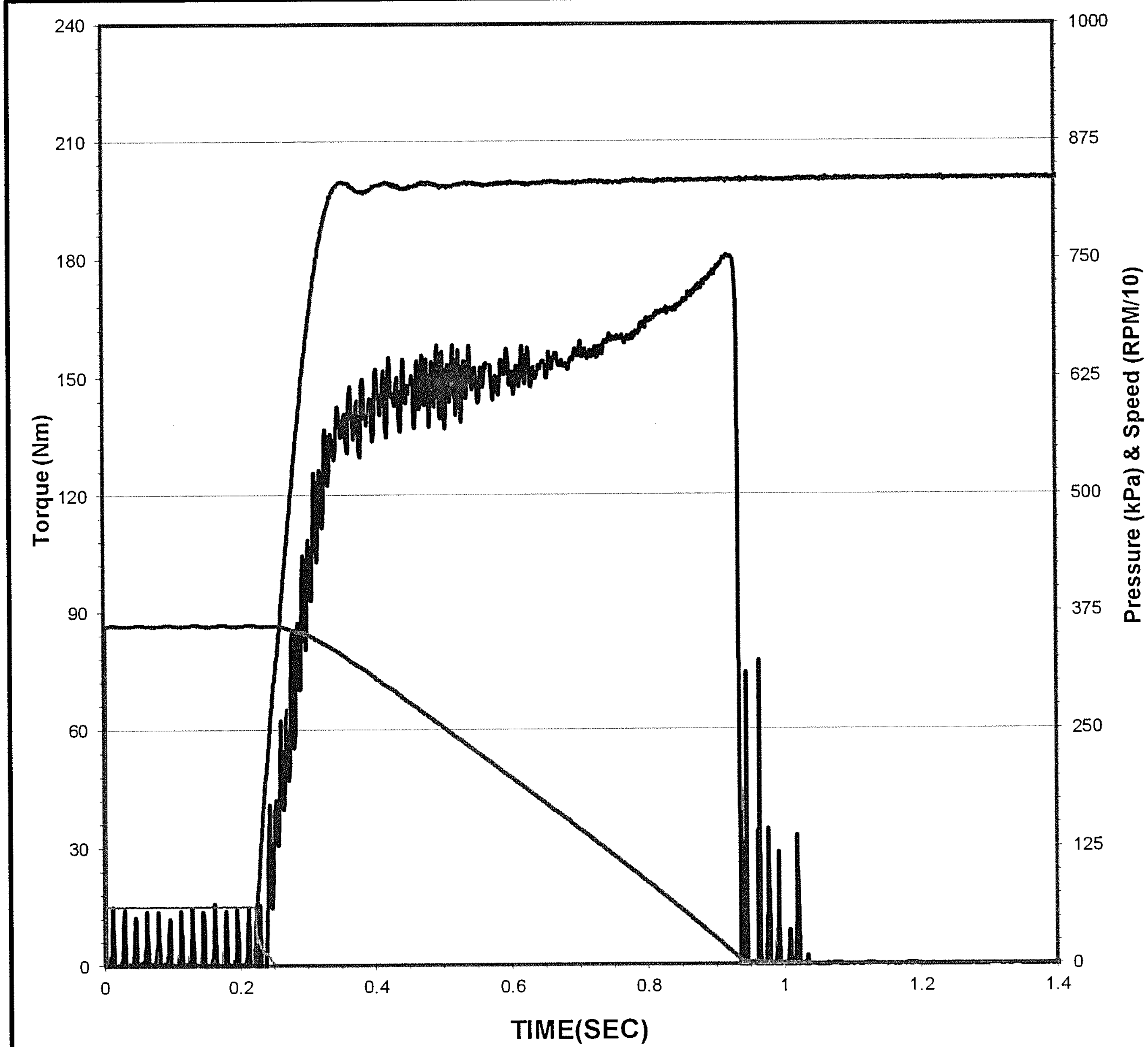
0.2 Sec Dyn:	145 N*m
Midpoint Dyn:	152 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	2:11:06
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1501
Temperature:	106.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.714 Sec

Torque

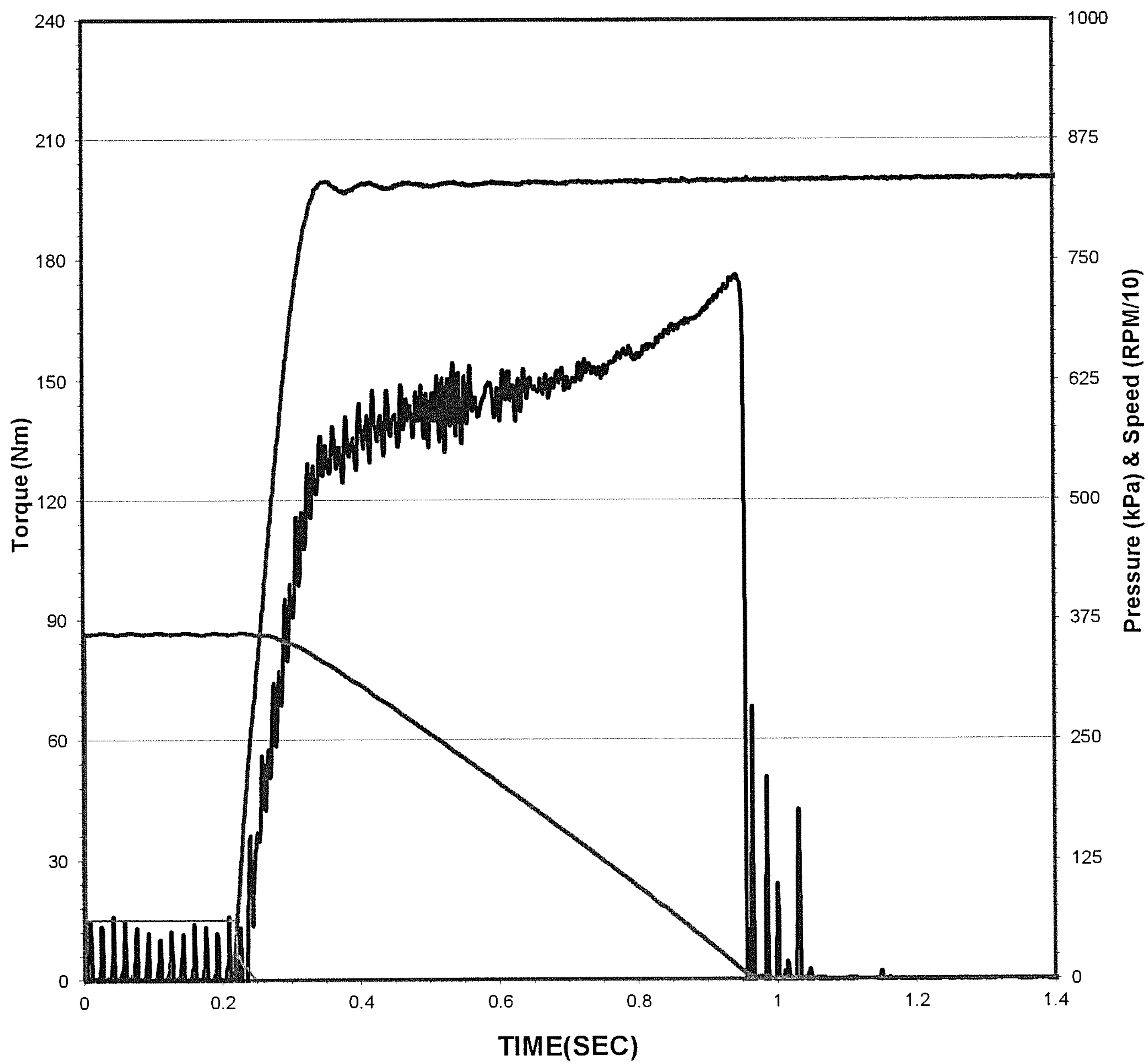
0.2 Sec Dyn:	147 N*m
Midpoint Dyn:	152 N*m
LwSpd Dynamic:	172 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.119

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	4:15:36
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	1999
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.738 Sec

Torque

0.2 Sec Dyn:	140 N*m
Midpoint Dyn:	147 N*m
LwSpd Dynamic:	169 N*m

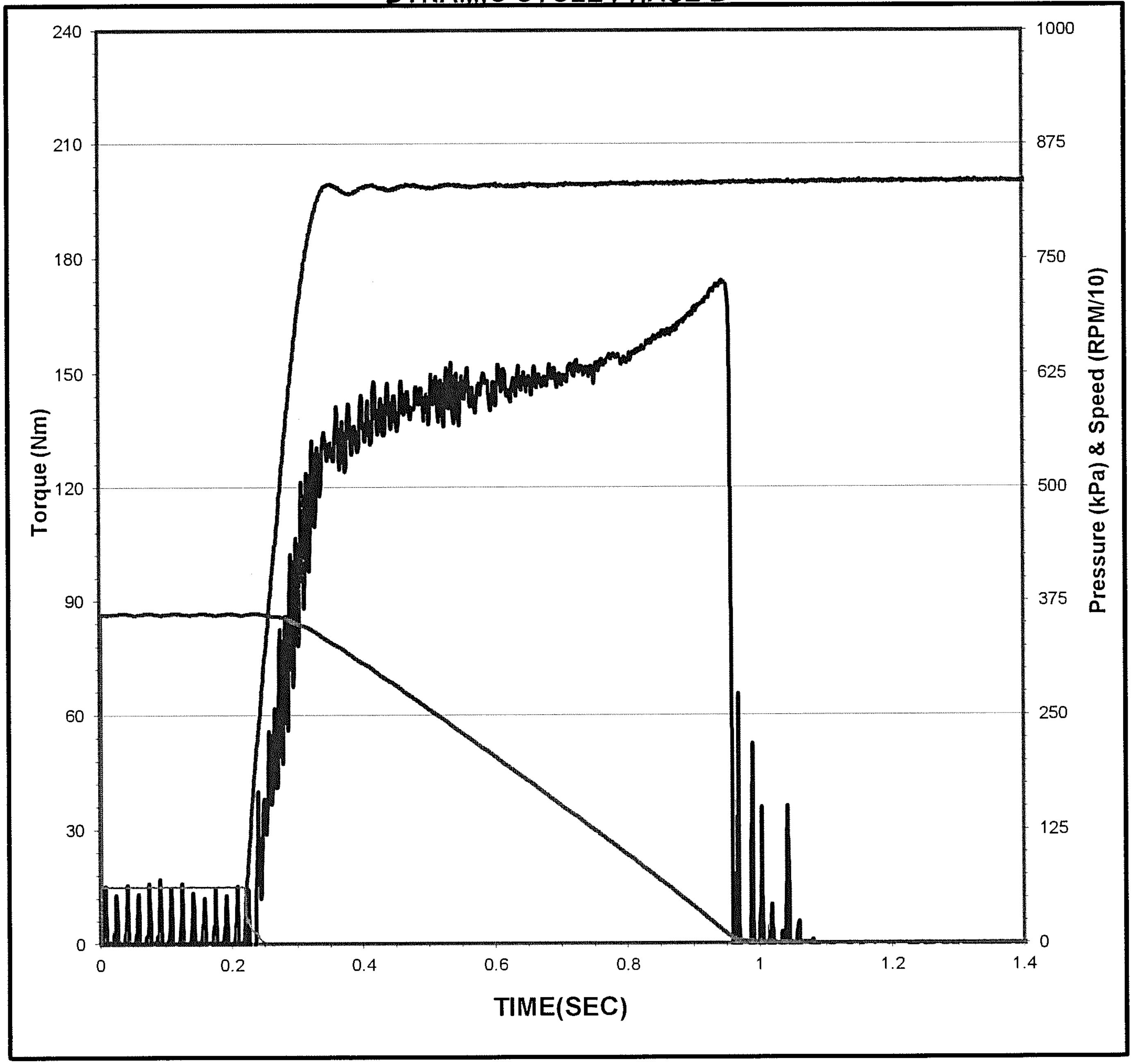
Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.117

A-132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	4:15:51
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	2000
Temperature:	110.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.74 Sec

Torque

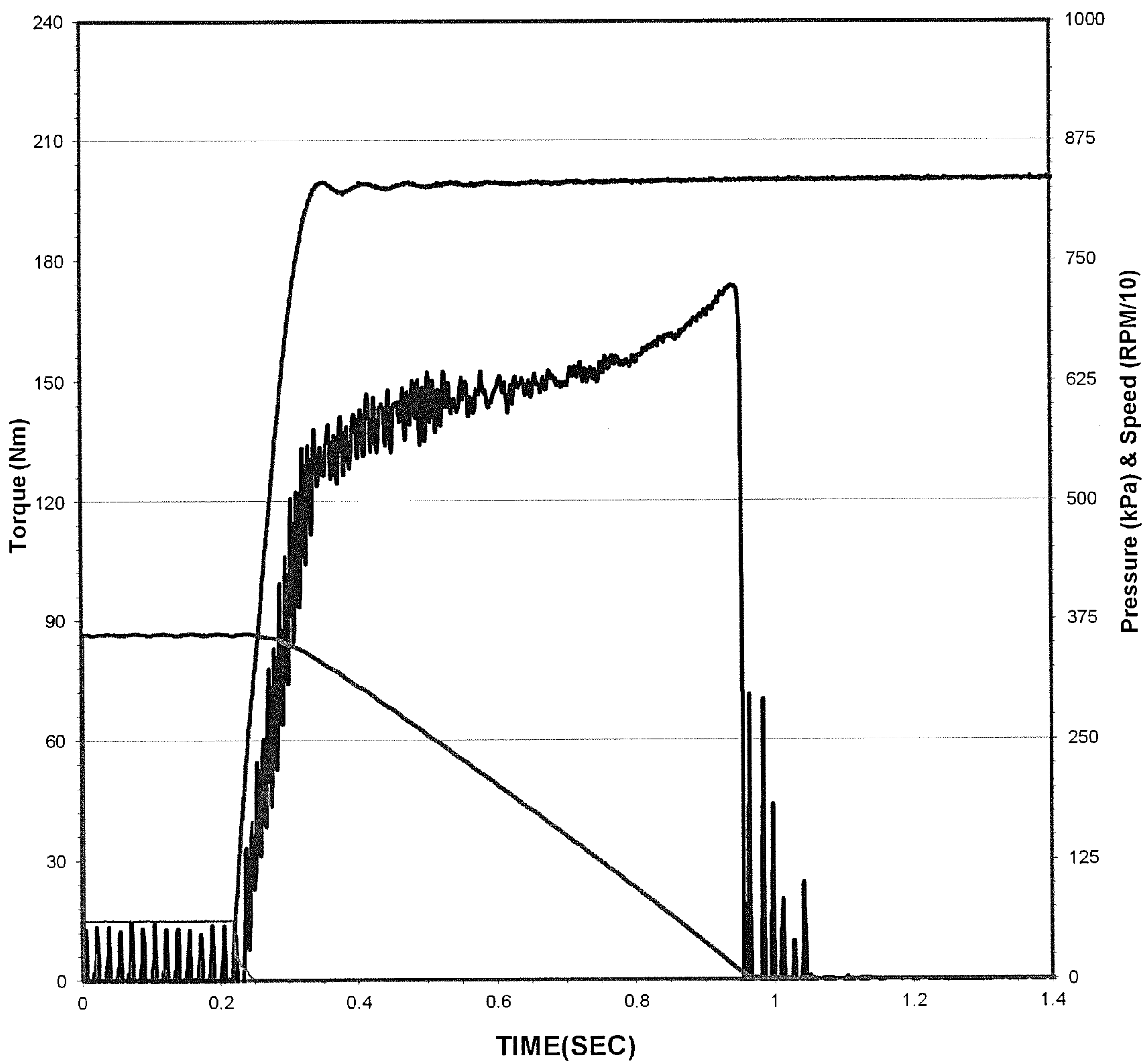
0.2 Sec Dyn:	140 N*m
Midpoint Dyn:	147 N*m
LwSpd Dynamic:	169 N*m

Coefficient of Friction

.2 Sec Dyn:	0.097
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.117

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	4:16:17
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	2001
Temperature:	107.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.737 Sec

Torque

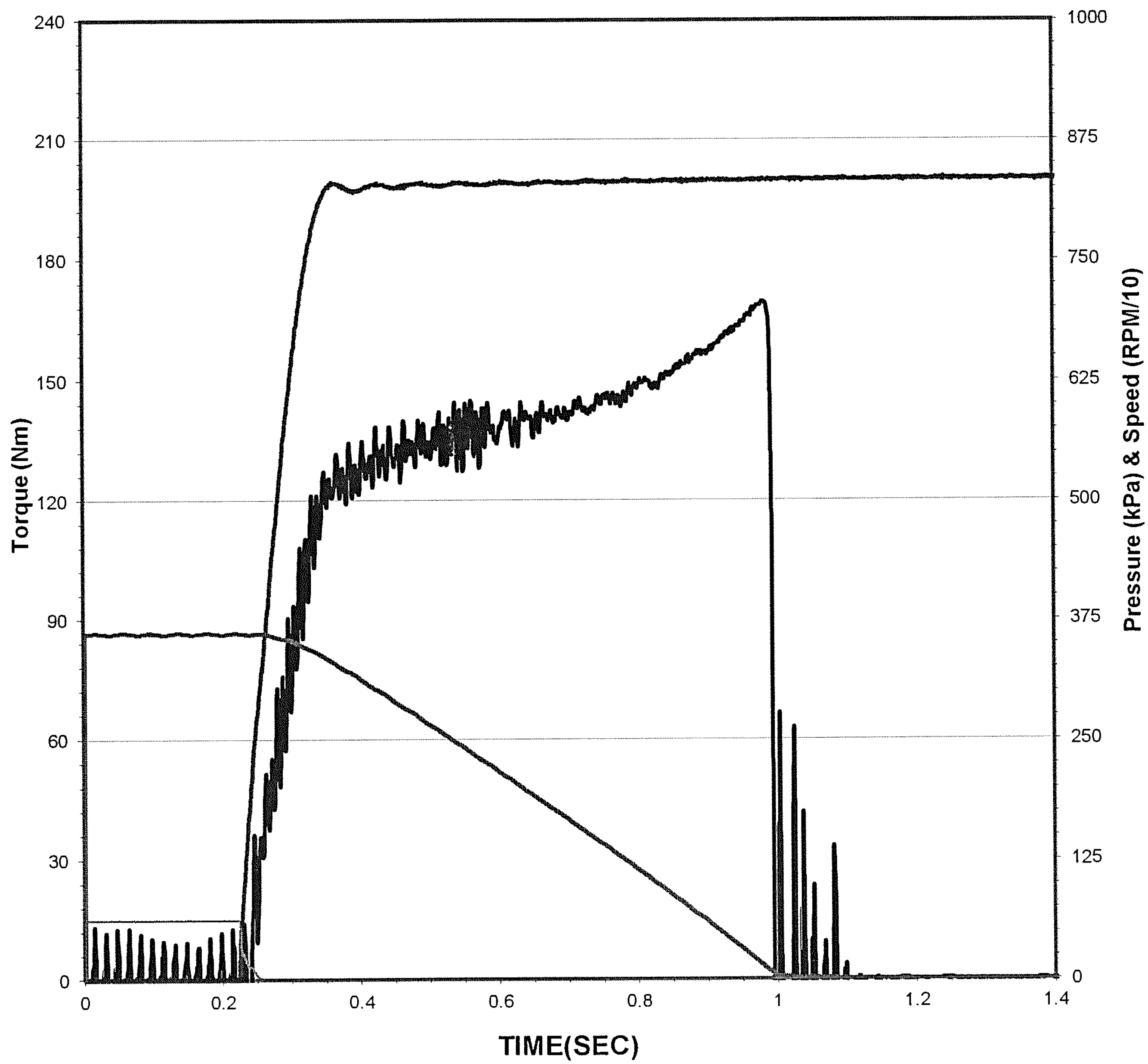
0.2 Sec Dyn:	142 N*m
Midpoint Dyn:	148 N*m
LwSpd Dynamic:	166 N*m

Coefficient of Friction

.2 Sec Dyn:	0.098
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.114

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 3/10/2014

Time of Test: 6:20:47

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 2499

Temperature: 110.8 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.771 Sec

Torque

0.2 Sec Dyn:	131 N*m
Midpoint Dyn:	140 N*m
LwSpd Dynamic:	164 N*m

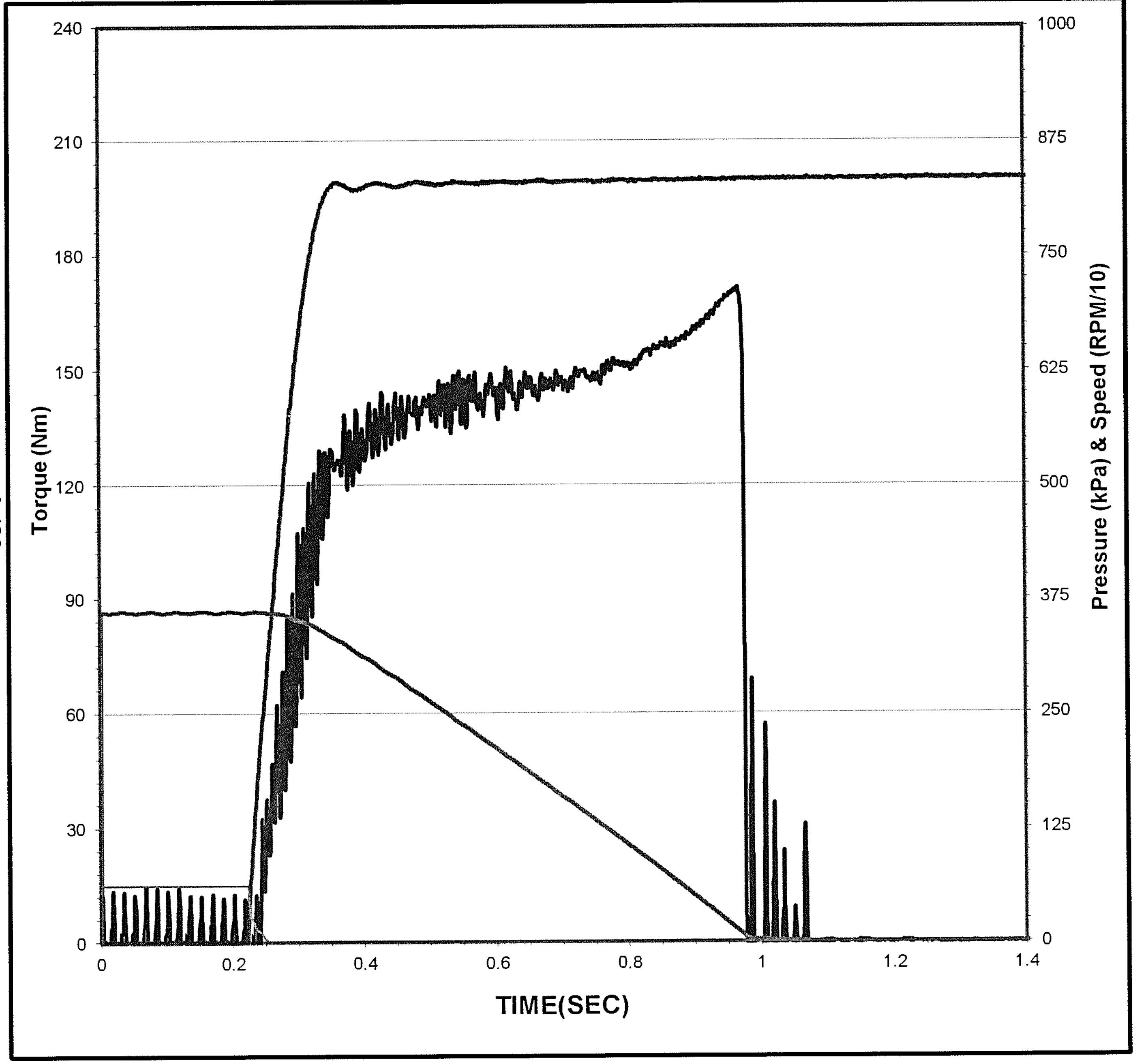
Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.113

A-135

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	6:21:03
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	2500
Temperature:	110.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.755 Sec

Torque

0.2 Sec Dyn:	137 N*m
Midpoint Dyn:	145 N*m
LwSpd Dynamic:	164 N*m

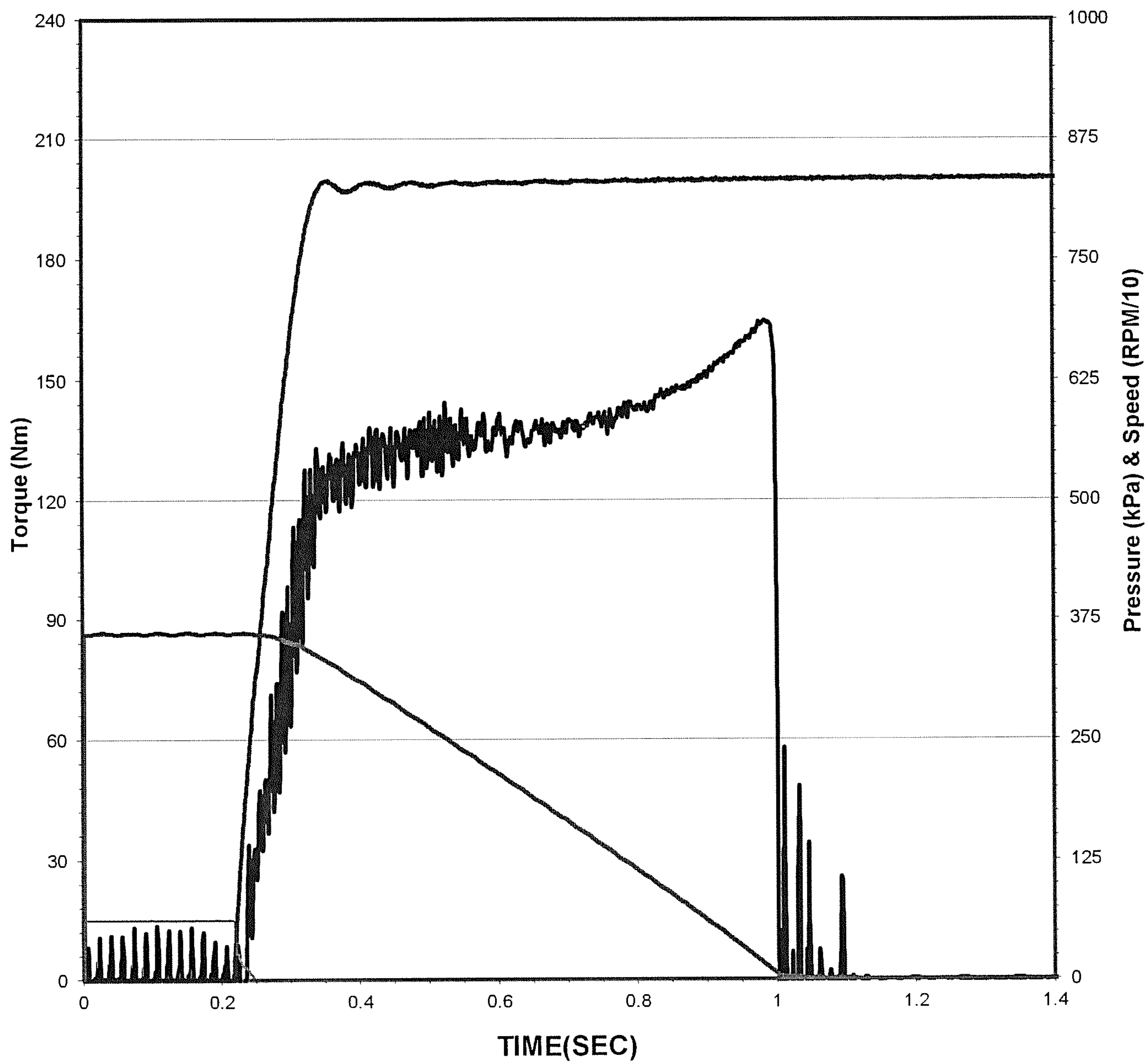
Coefficient of Friction

.2 Sec Dyn:	0.095
Midpoint Dyn:	0.100
LwSpd Dynamic:	0.113

A-136

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	6:21:29
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	2501
Temperature:	107.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.785 Sec

Torque

0.2 Sec Dyn:	133 N*m
Midpoint Dyn:	138 N*m
LwSpd Dynamic:	155 N*m

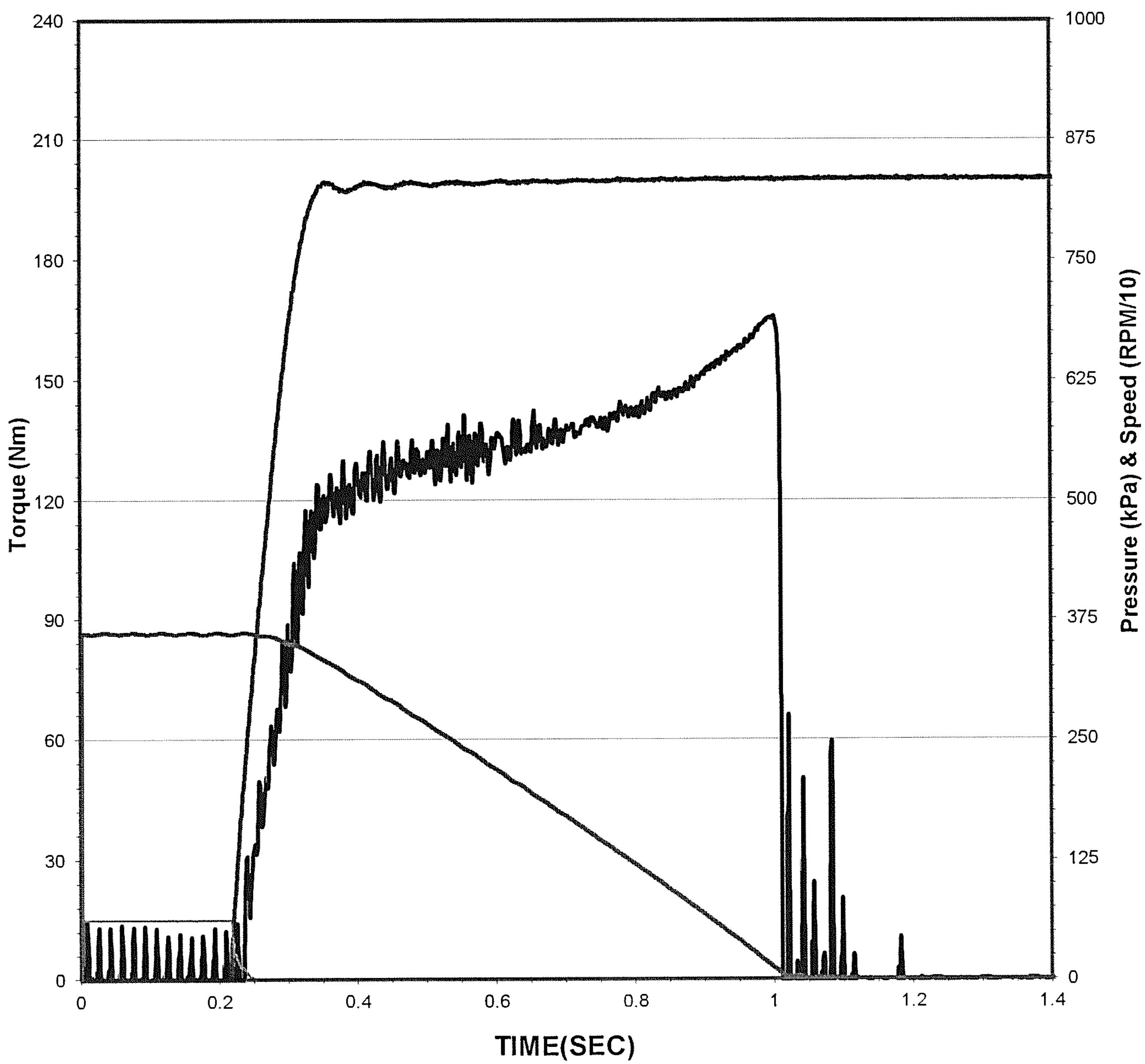
Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.107

A-137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	8:25:59
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	2999
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.795 Sec

Torque

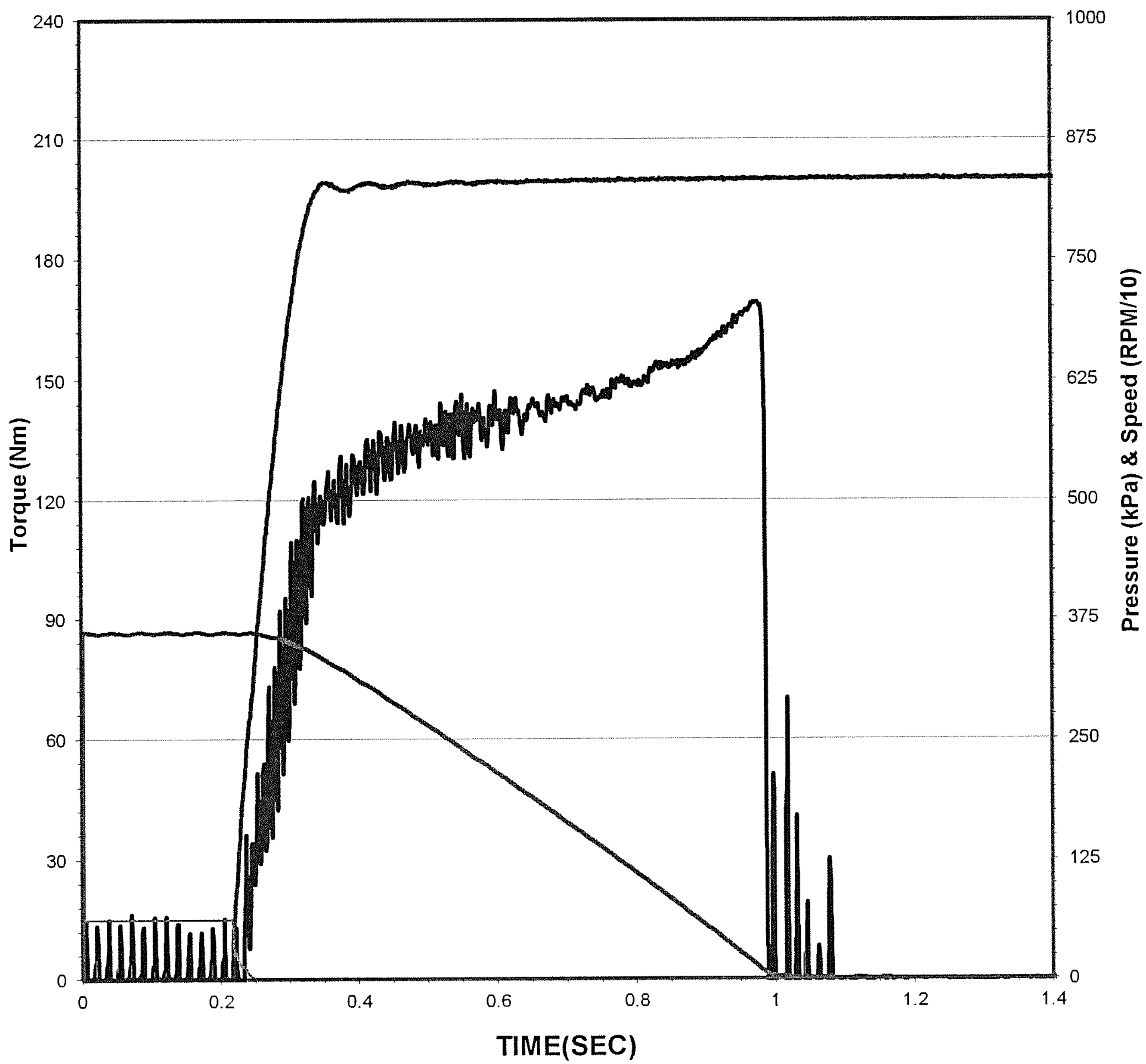
0.2 Sec Dyn:	127 N*m
Midpoint Dyn:	135 N*m
LwSpd Dynamic:	157 N*m

Coefficient of Friction

.2 Sec Dyn:	0.088
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.108

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



A-139

Date of Test: 3/10/2014

Time of Test: 8:26:14

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 3000

Temperature: 110.9 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.773 Sec

Torque

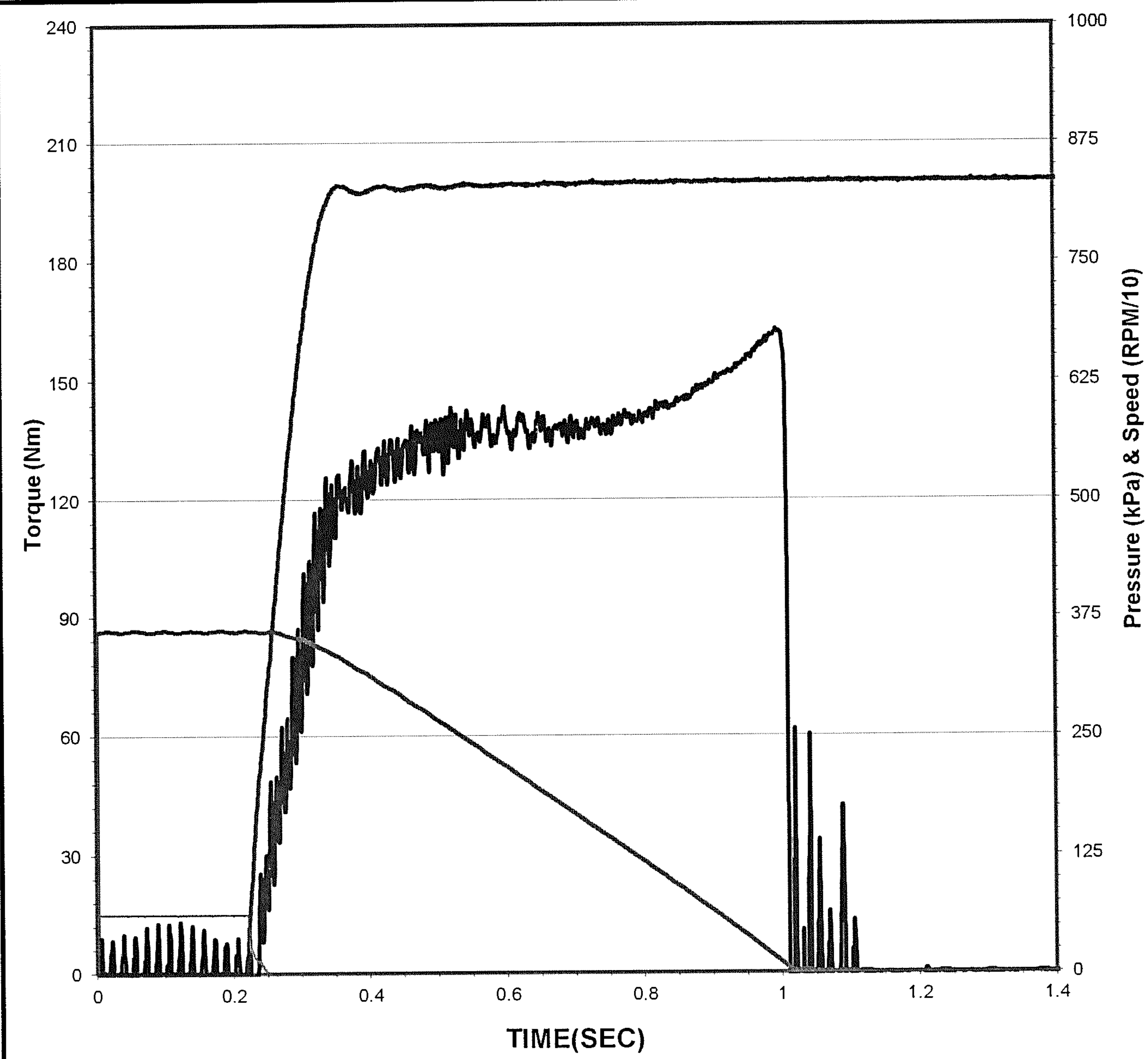
0.2 Sec Dyn:	131 N*m
Midpoint Dyn:	141 N*m
LwSpd Dynamic:	164 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.098
LwSpd Dynamic:	0.113

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



A-140

Date of Test:	3/10/2014
Time of Test:	8:26:41
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	3001
Temperature:	107.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.79 Sec

Torque

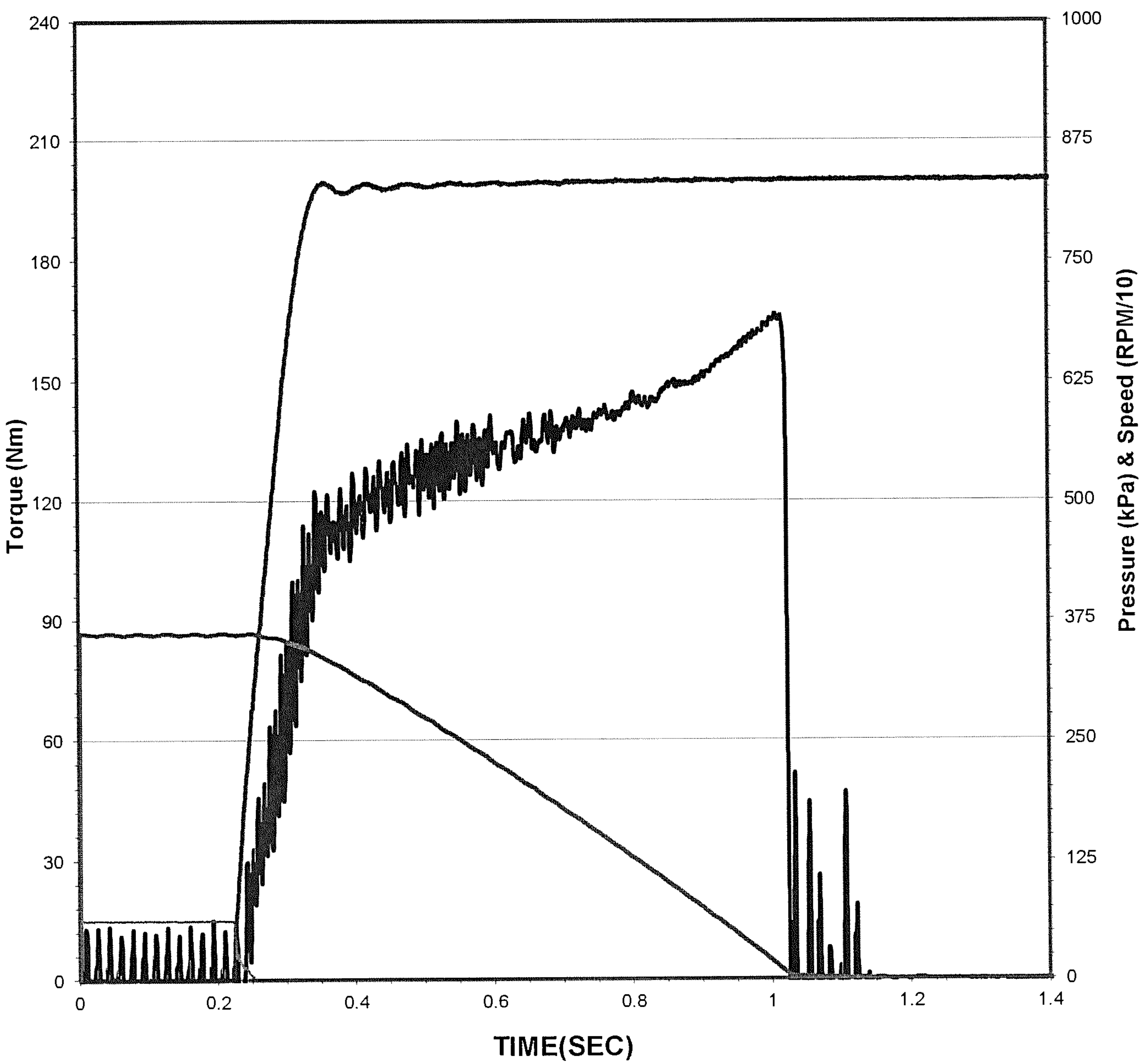
0.2 Sec Dyn:	130 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	156 N*m

Coefficient of Friction

.2 Sec Dyn:	0.090
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.108

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 3/10/2014

Time of Test: 10:31:11

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 3499

Temperature: 111.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.802 Sec

Torque

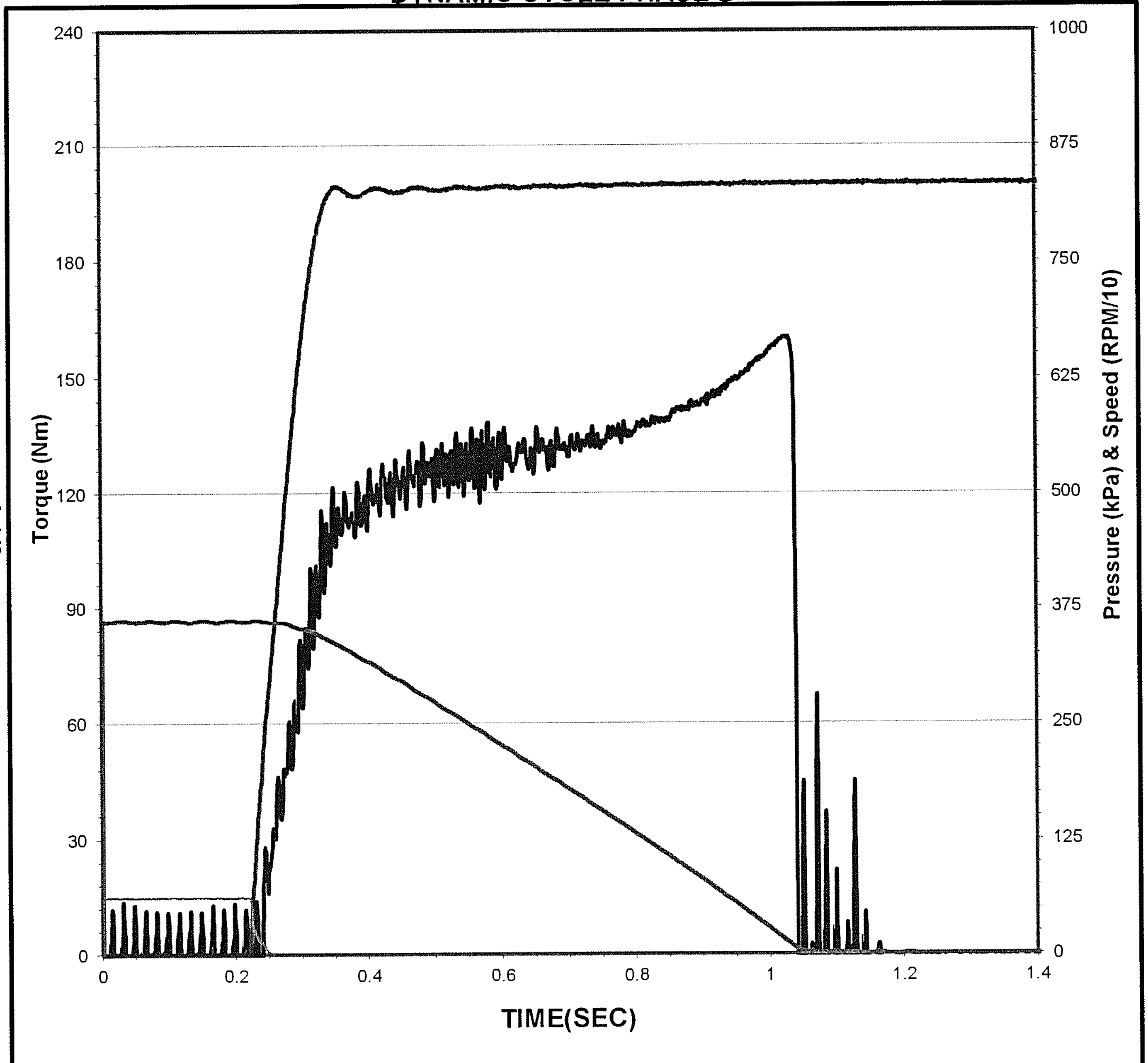
0.2 Sec Dyn:	123 N*m
Midpoint Dyn:	135 N*m
LwSpd Dynamic:	159 N*m

Coefficient of Friction

.2 Sec Dyn:	0.085
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.110

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 3/10/2014

Time of Test: 10:31:26

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 3500

Temperature: 111.5 °C (112.7 ± 3.0 °C)

Apply Pressure: 830 kPa 827 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.5 KJ (18.71 ± 0.40 KJ)

Engage Time: 0.82 Sec

Torque

0.2 Sec Dyn: 122 N*m
Midpoint Dyn: 131 N*m
LwSpd Dynamic: 153 N*m

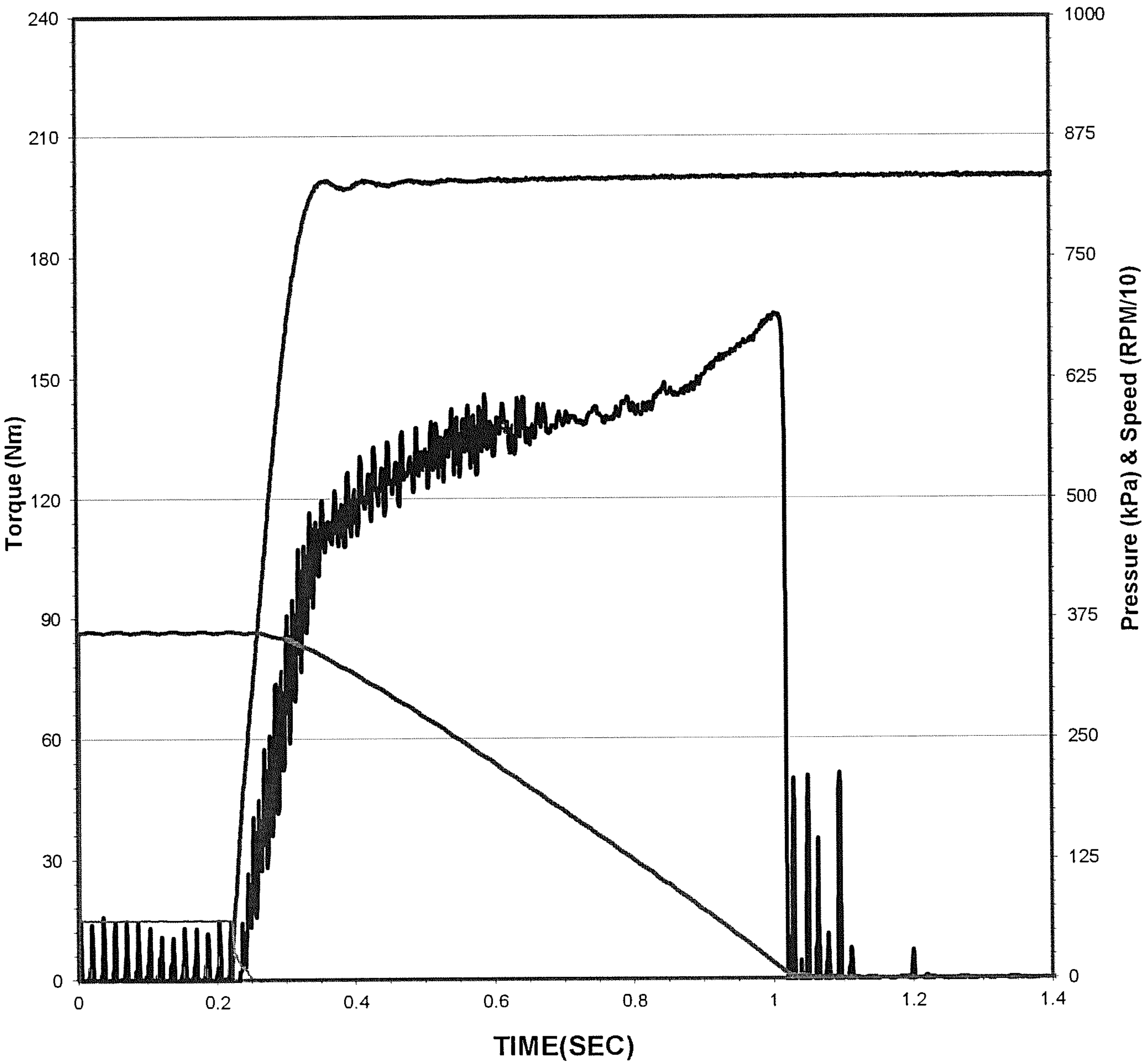
Coefficient of Friction

.2 Sec Dyn: 0.085
Midpoint Dyn: 0.091
LwSpd Dynamic: 0.105

A-142

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	10:31:53
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	3501
Temperature:	107.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.798 Sec

Torque

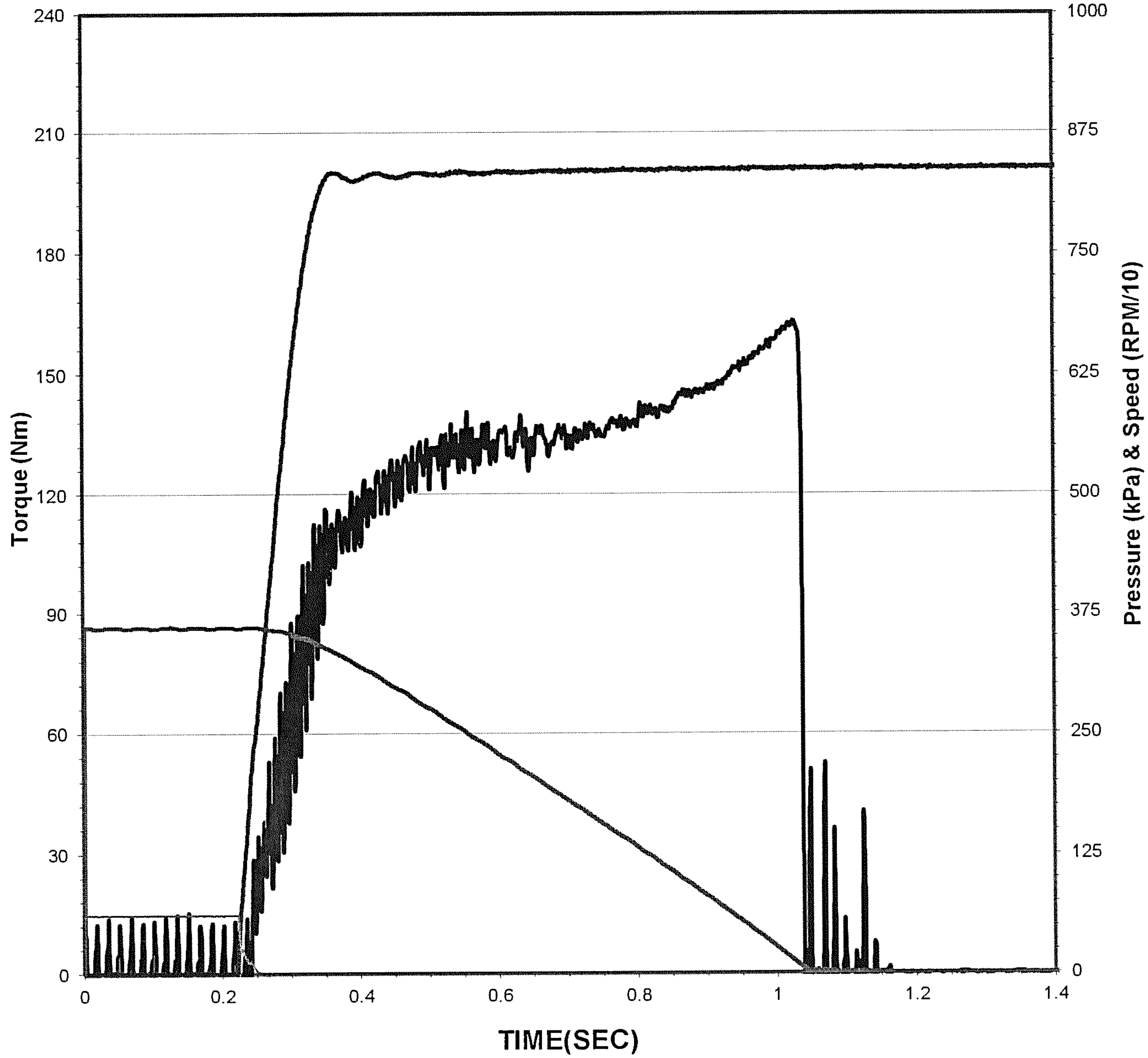
0.2 Sec Dyn:	124 N*m
Midpoint Dyn:	139 N*m
LwSpd Dynamic:	159 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.110

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	12:36:23
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	3999
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	834 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.816 Sec

Torque

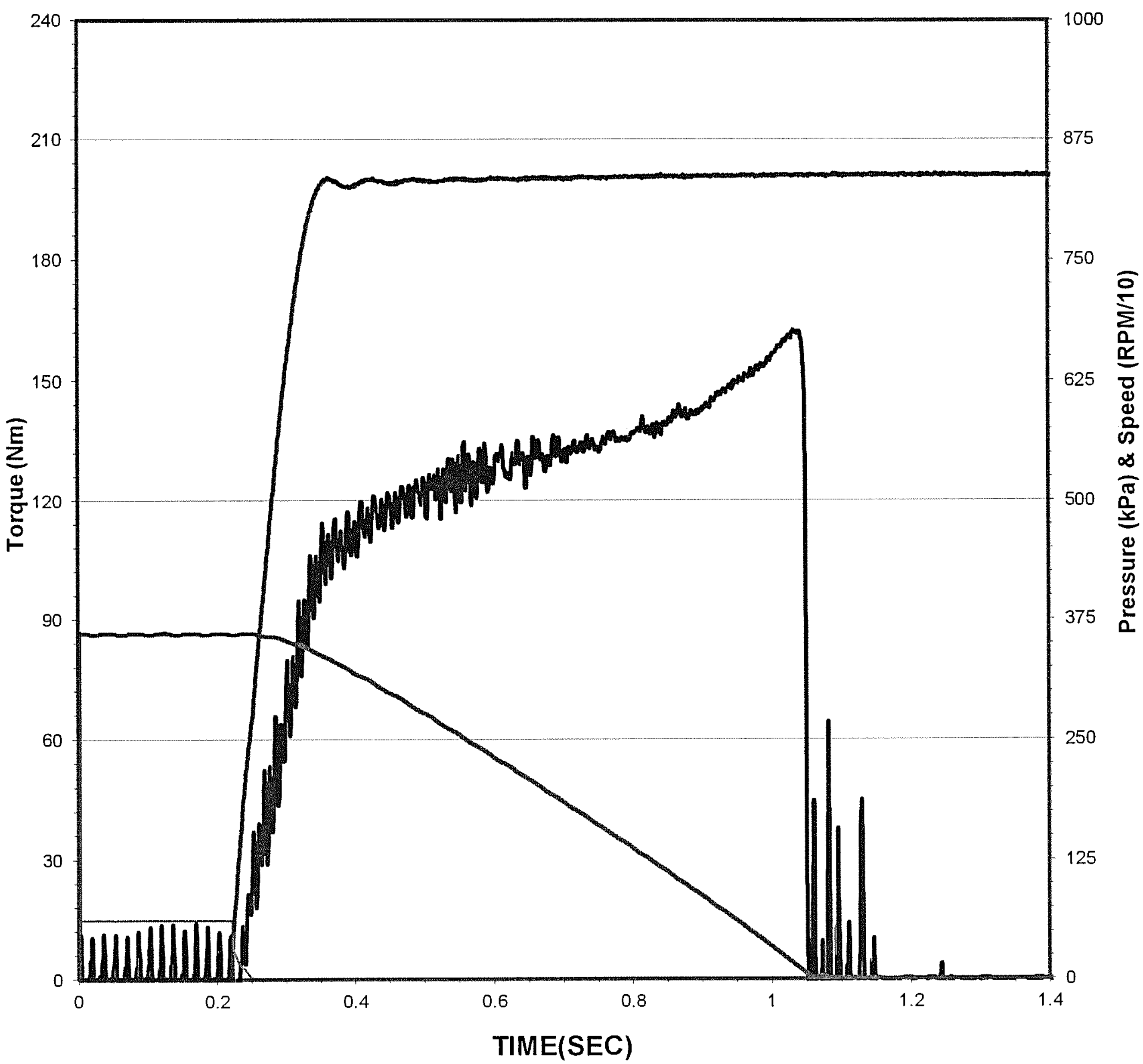
0.2 Sec Dyn:	122 N*m
Midpoint Dyn:	134 N*m
LwSpd Dynamic:	157 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.108

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	12:36:38
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4000
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.831 Sec

Torque

0.2 Sec Dyn:	117 N*m
Midpoint Dyn:	131 N*m
LwSpd Dynamic:	155 N*m

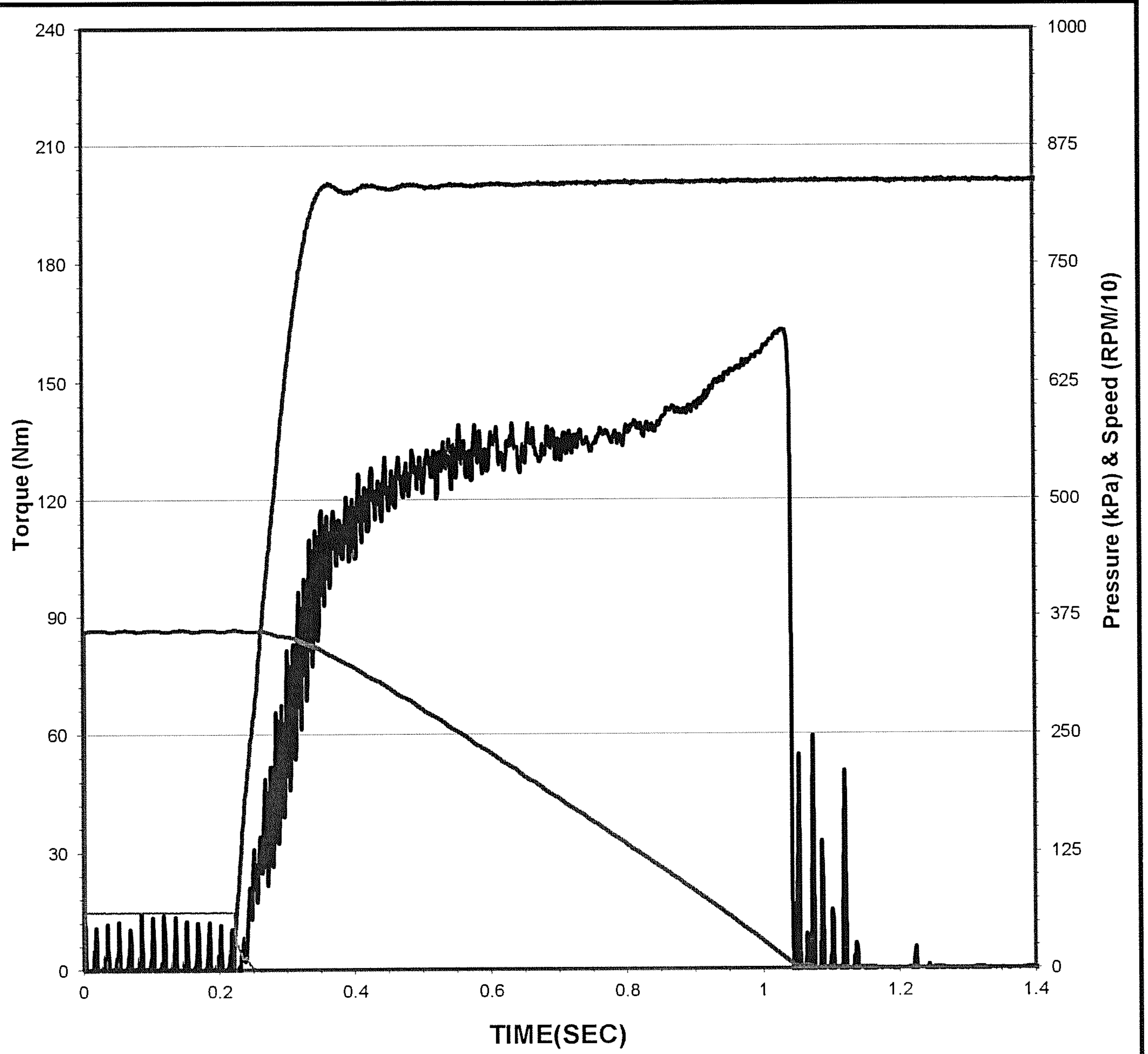
Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.107

A-145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	12:37:05
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4001
Temperature:	107.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.822 Sec

Torque

0.2 Sec Dyn:	122 N*m
Midpoint Dyn:	134 N*m
LwSpd Dynamic:	156 N*m

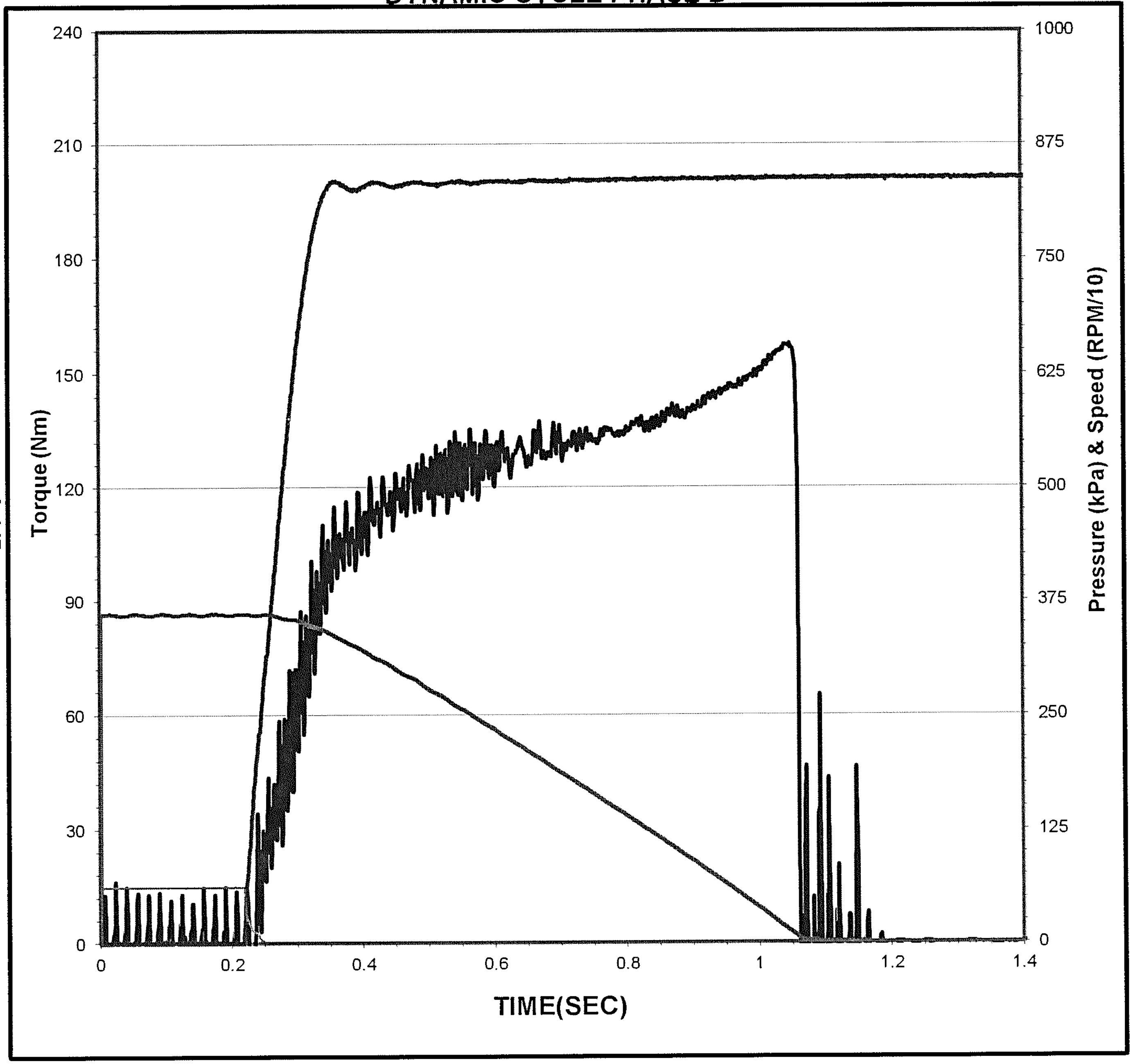
Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.108

A-146

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	14:41:35
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4499
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	834 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.843 Sec

Torque

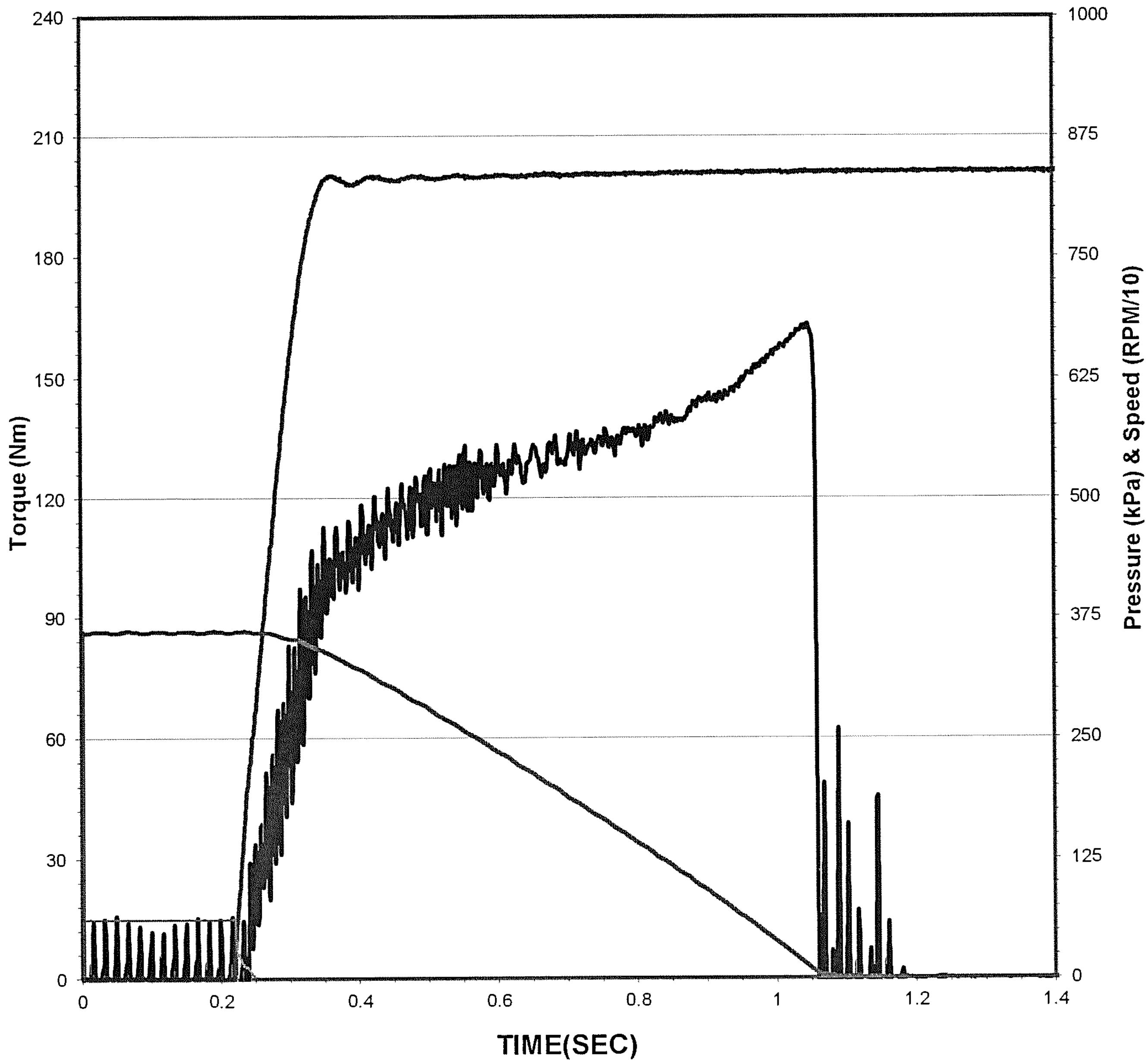
0.2 Sec Dyn:	115 N*m
Midpoint Dyn:	130 N*m
LwSpd Dynamic:	150 N*m

Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.104

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	14:41:50
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4500
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.84 Sec

Torque

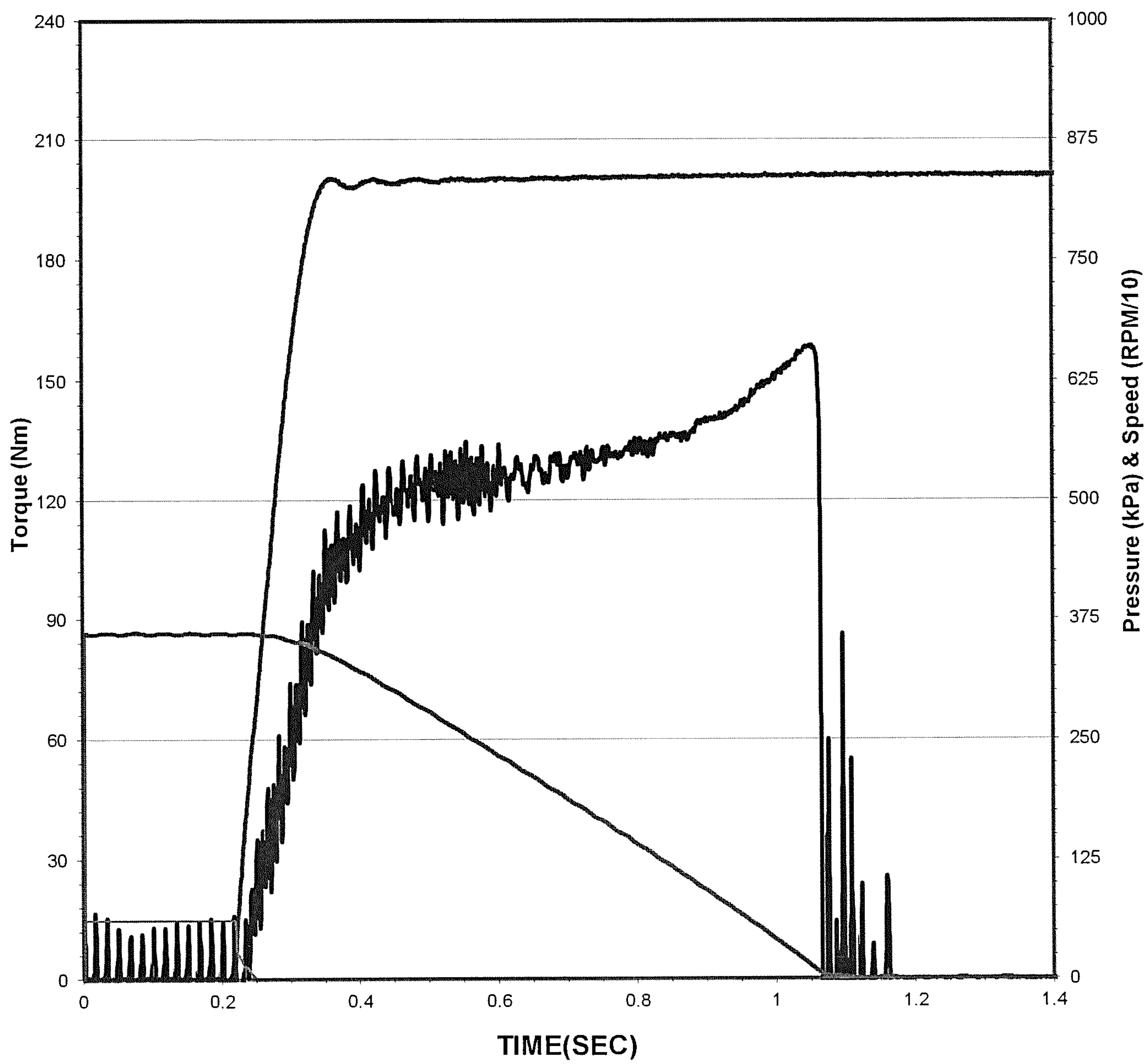
0.2 Sec Dyn:	114 N*m
Midpoint Dyn:	130 N*m
LwSpd Dynamic:	155 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.107

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



A-149

Date of Test:	3/10/2014
Time of Test:	14:42:16
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4501
Temperature:	107.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.847 Sec

Torque

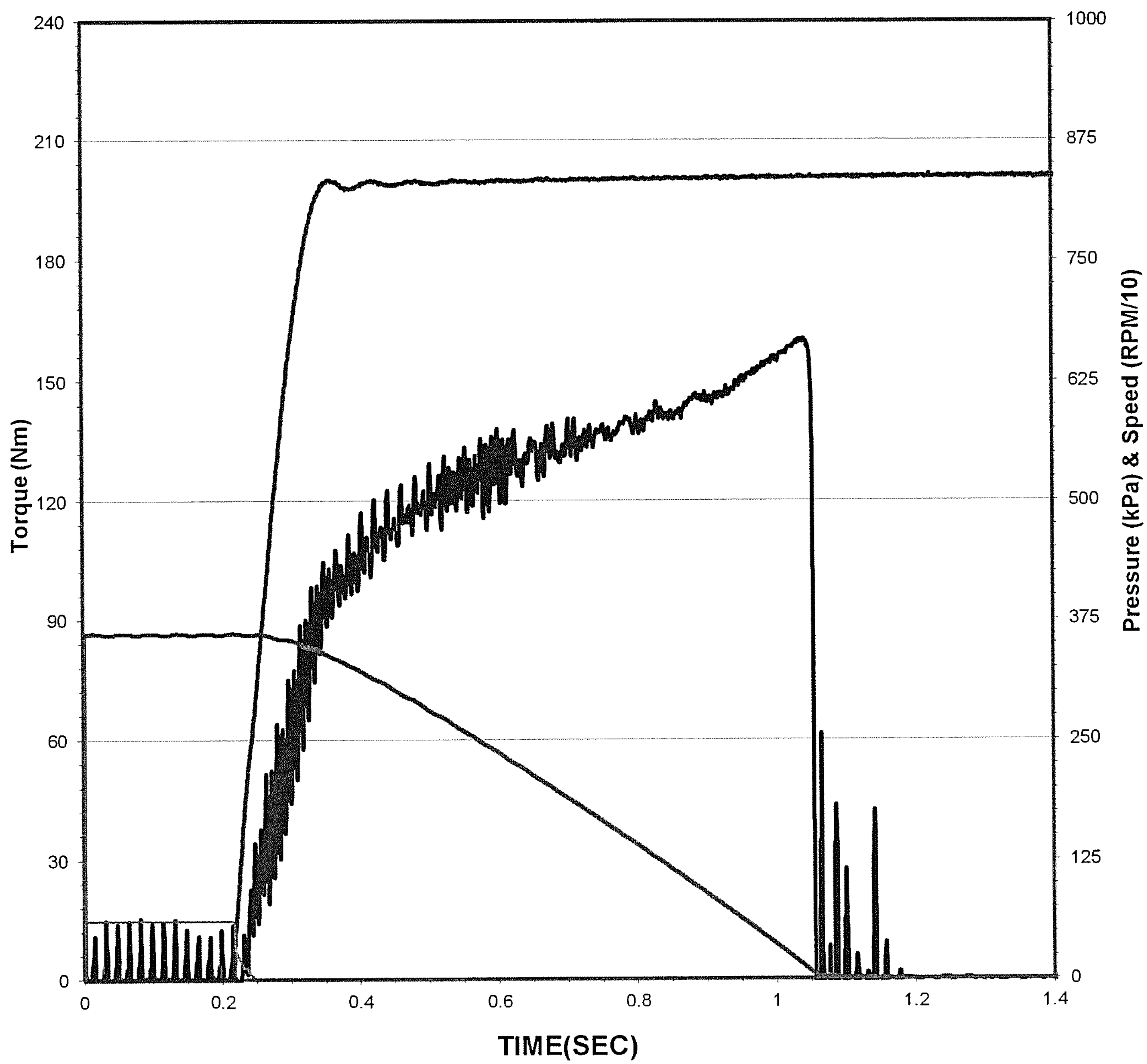
0.2 Sec Dyn:	119 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	150 N*m

Coefficient of Friction

.2 Sec Dyn:	0.082
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.103

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	16:46:46
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	4999
Temperature:	111.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.839 Sec

Torque

0.2 Sec Dyn:	111 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	155 N*m

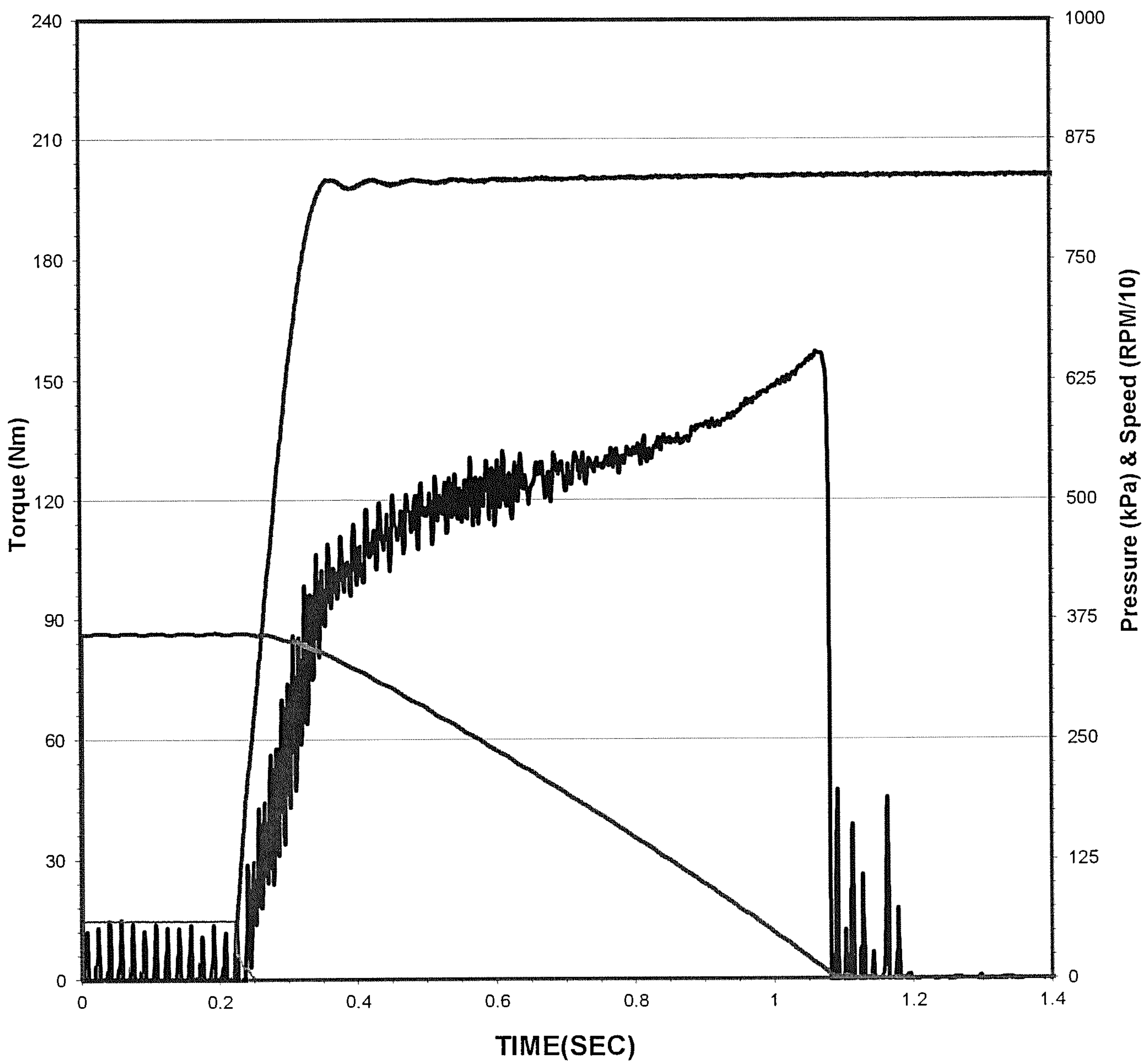
Coefficient of Friction

.2 Sec Dyn:	0.077
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.107

A-150

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	16:47:02
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	5000
Temperature:	111.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.861 Sec

Torque

0.2 Sec Dyn:	110 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	148 N*m

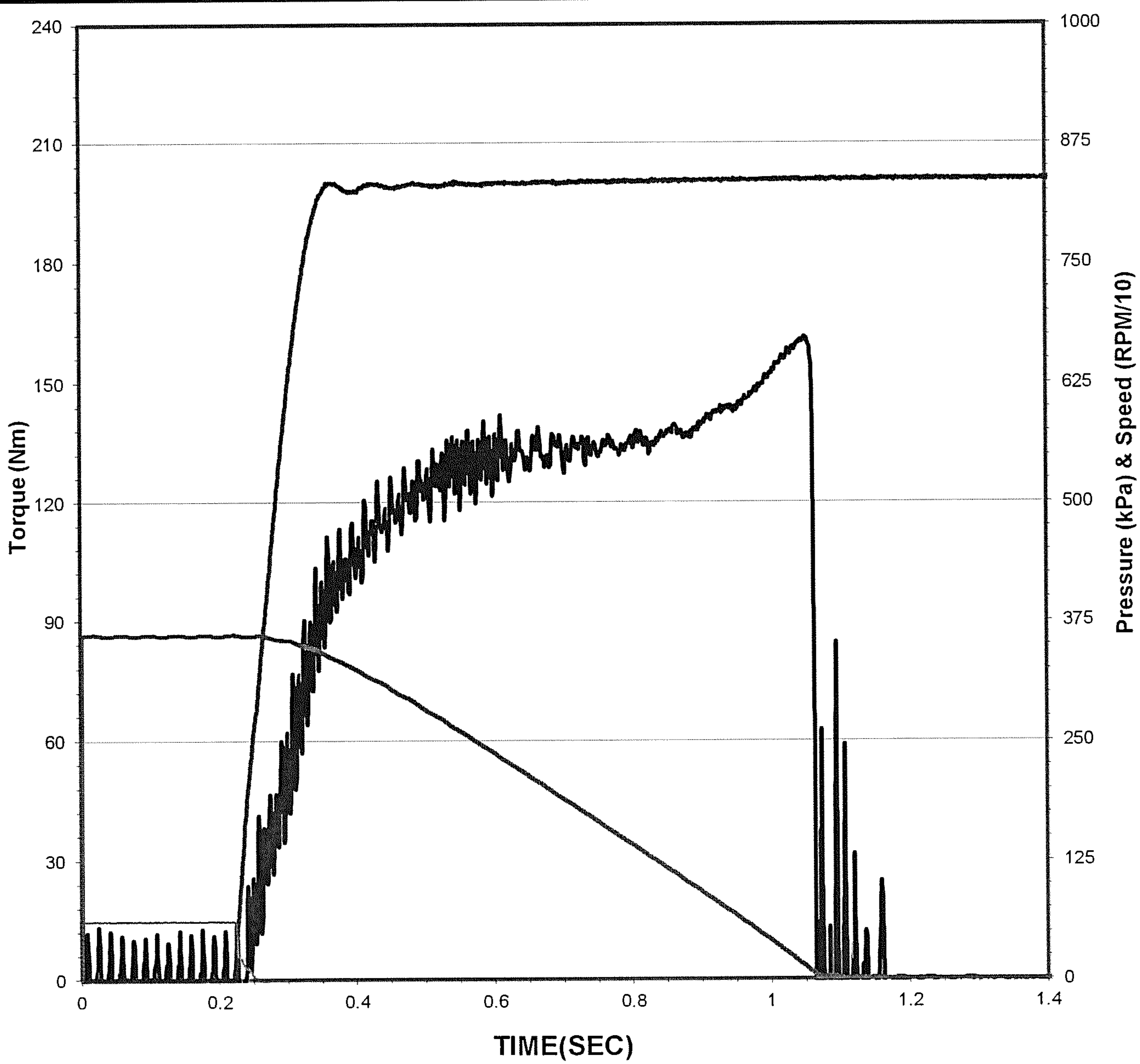
Coefficient of Friction

.2 Sec Dyn:	0.076
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.102

A-151

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 3/10/2014

Time of Test: 16:47:28

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 5001

Temperature: 107.5 °C (112.7 ± 3.0 °C)

Apply Pressure: 833 kPa 827 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.4 KJ (18.71 ± 0.40 KJ)

Engage Time: 0.84 Sec

Torque

0.2 Sec Dyn: 114 N*m
Midpoint Dyn: 134 N*m
LwSpd Dynamic: 156 N*m

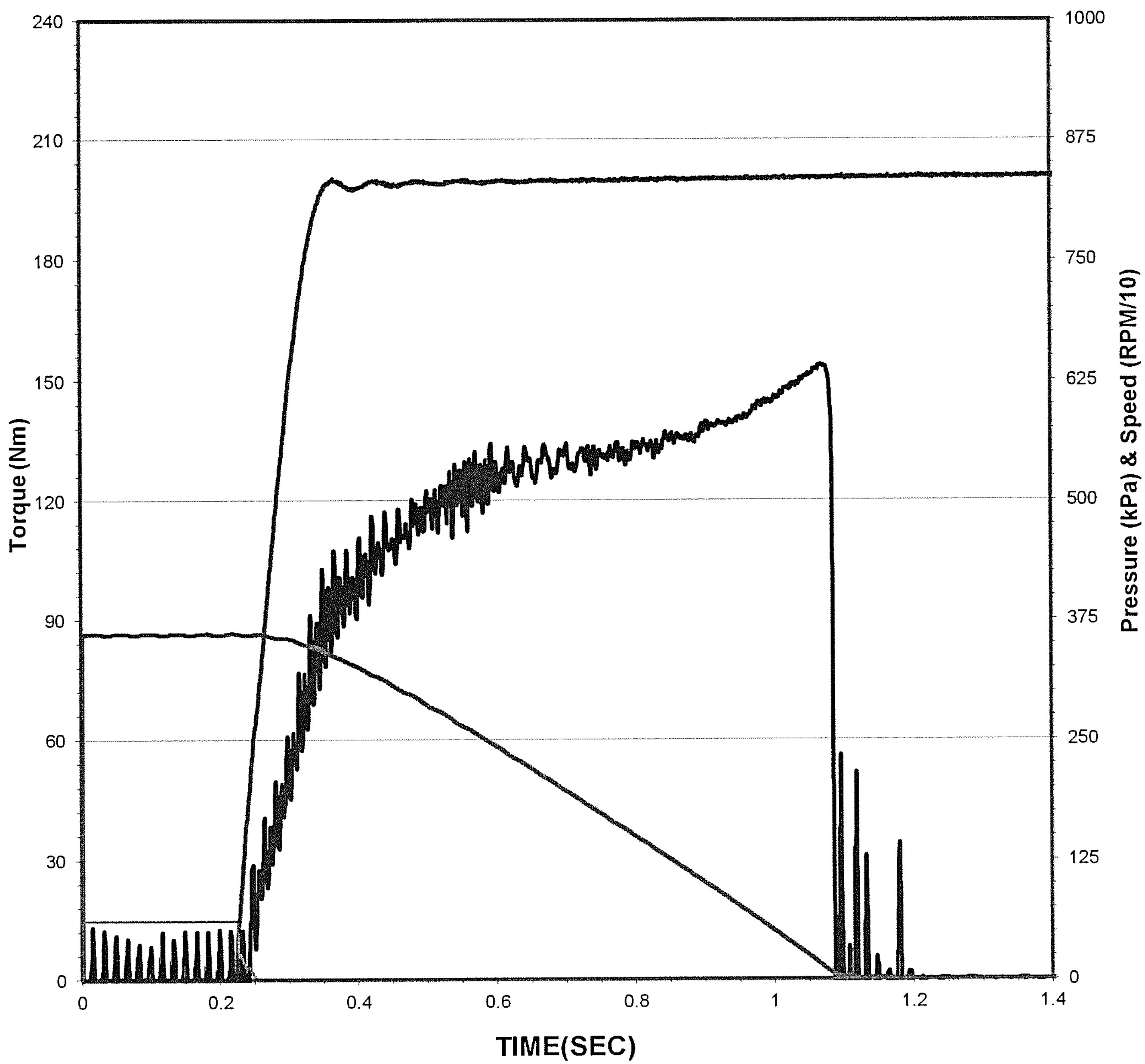
Coefficient of Friction

.2 Sec Dyn: 0.079
Midpoint Dyn: 0.092
LwSpd Dynamic: 0.108

A-152

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



A-153

Date of Test: 3/10/2014

Time of Test: 18:51:43

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 5498

Temperature: 111.1 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.863 Sec

Torque

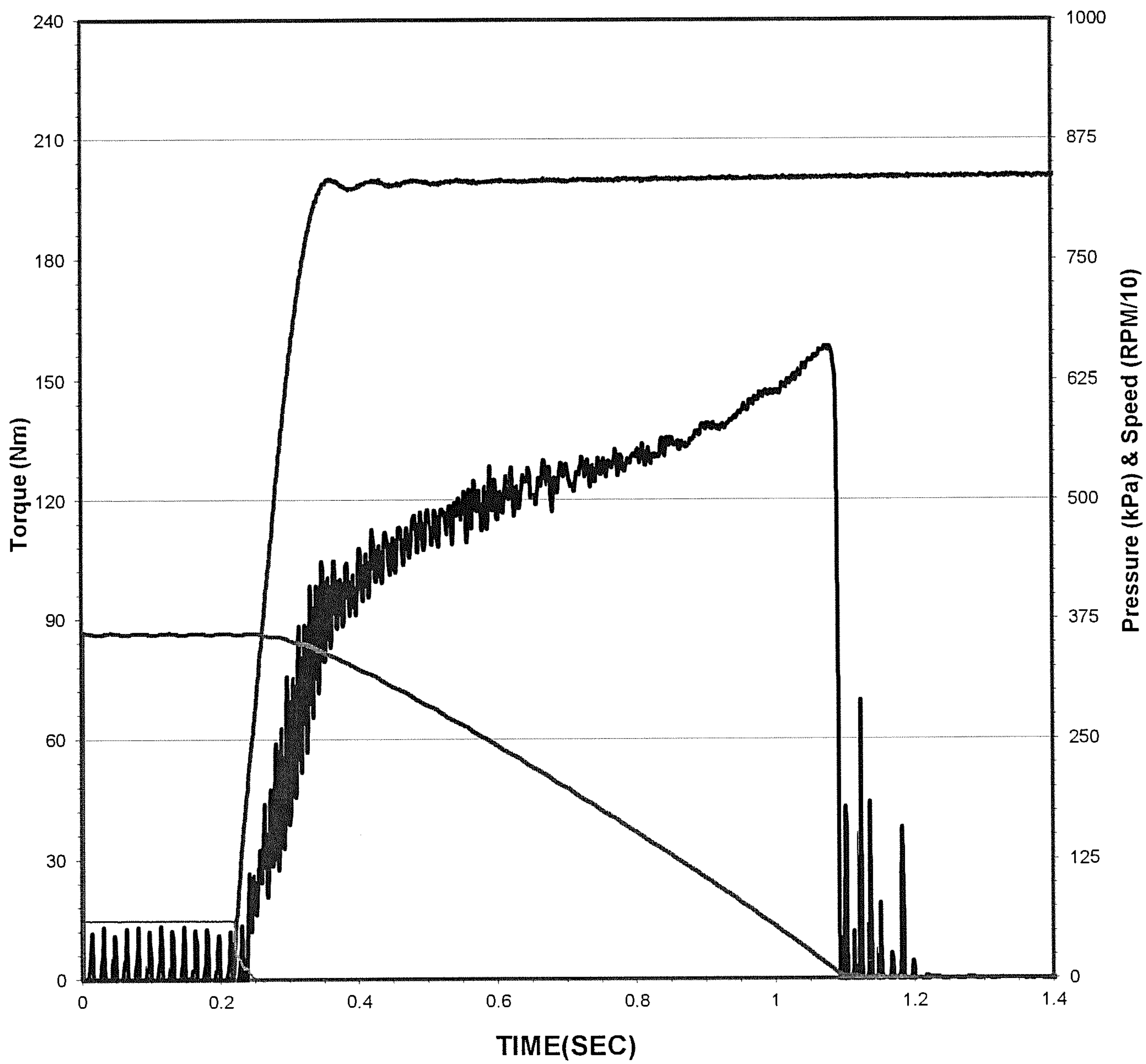
0.2 Sec Dyn:	108 N*m
Midpoint Dyn:	131 N*m
LwSpd Dynamic:	147 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.102

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 3/10/2014

Time of Test: 18:51:58

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 5499

Temperature: 111.0 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.874 Sec

Torque

0.2 Sec Dyn: 105 N*m
Midpoint Dyn: 125 N*m
LwSpd Dynamic: 149 N*m

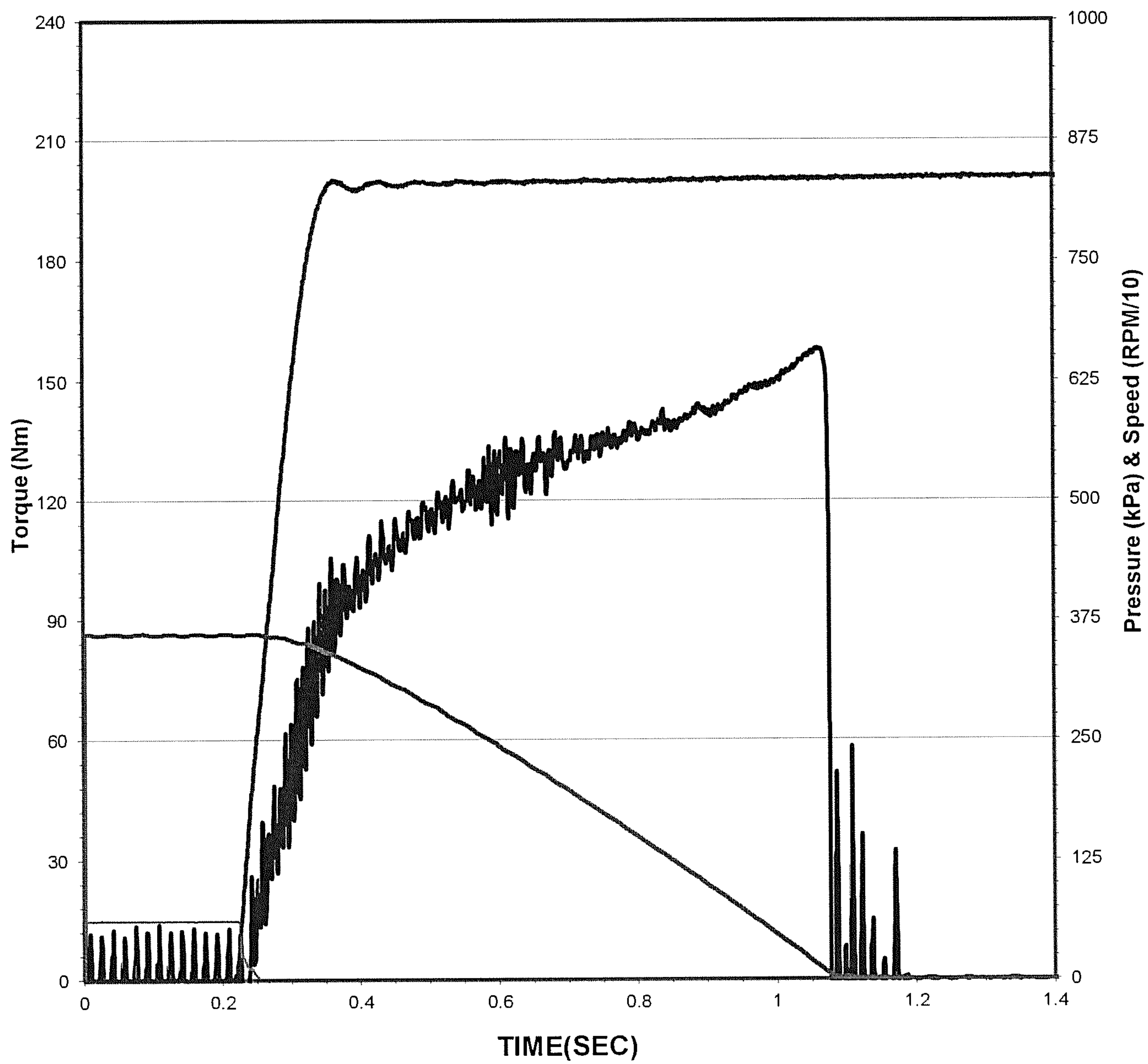
Coefficient of Friction

.2 Sec Dyn: 0.072
Midpoint Dyn: 0.087
LwSpd Dynamic: 0.103

A-154

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	3/10/2014
Time of Test:	18:52:13
Test Number:	C4-8-1459
Fluid Code:	LO306520
Cycle Number:	5500
Temperature:	110.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.853 Sec

Torque

0.2 Sec Dyn:	106 N*m
Midpoint Dyn:	130 N*m
LwSpd Dynamic:	153 N*m

Coefficient of Friction

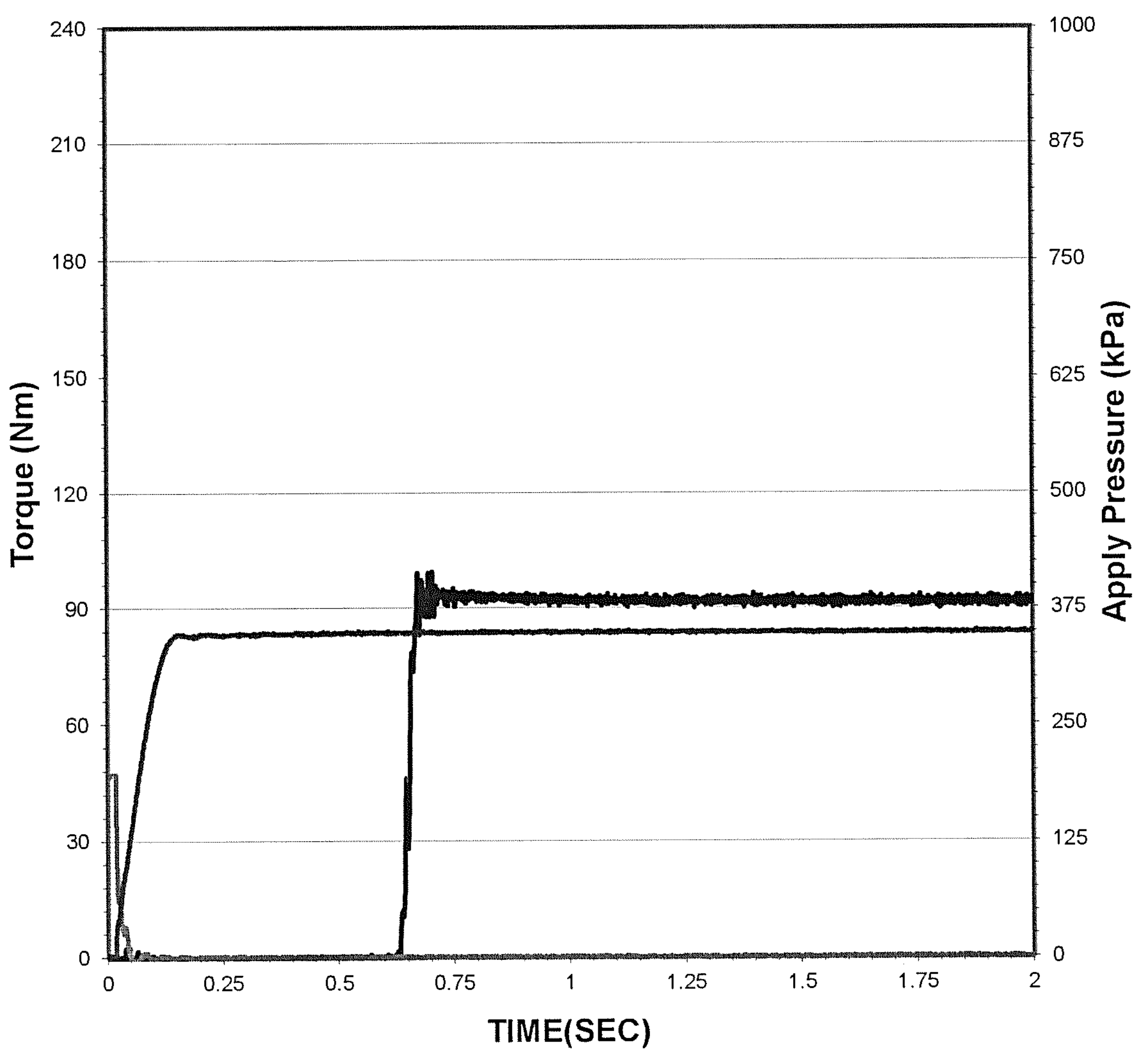
.2 Sec Dyn:	0.073
Midpoint Dyn:	0.090
LwSpd Dynamic:	0.105

A-155

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/9/2014

Time of Test: 19:33:33

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 10

PHASE A

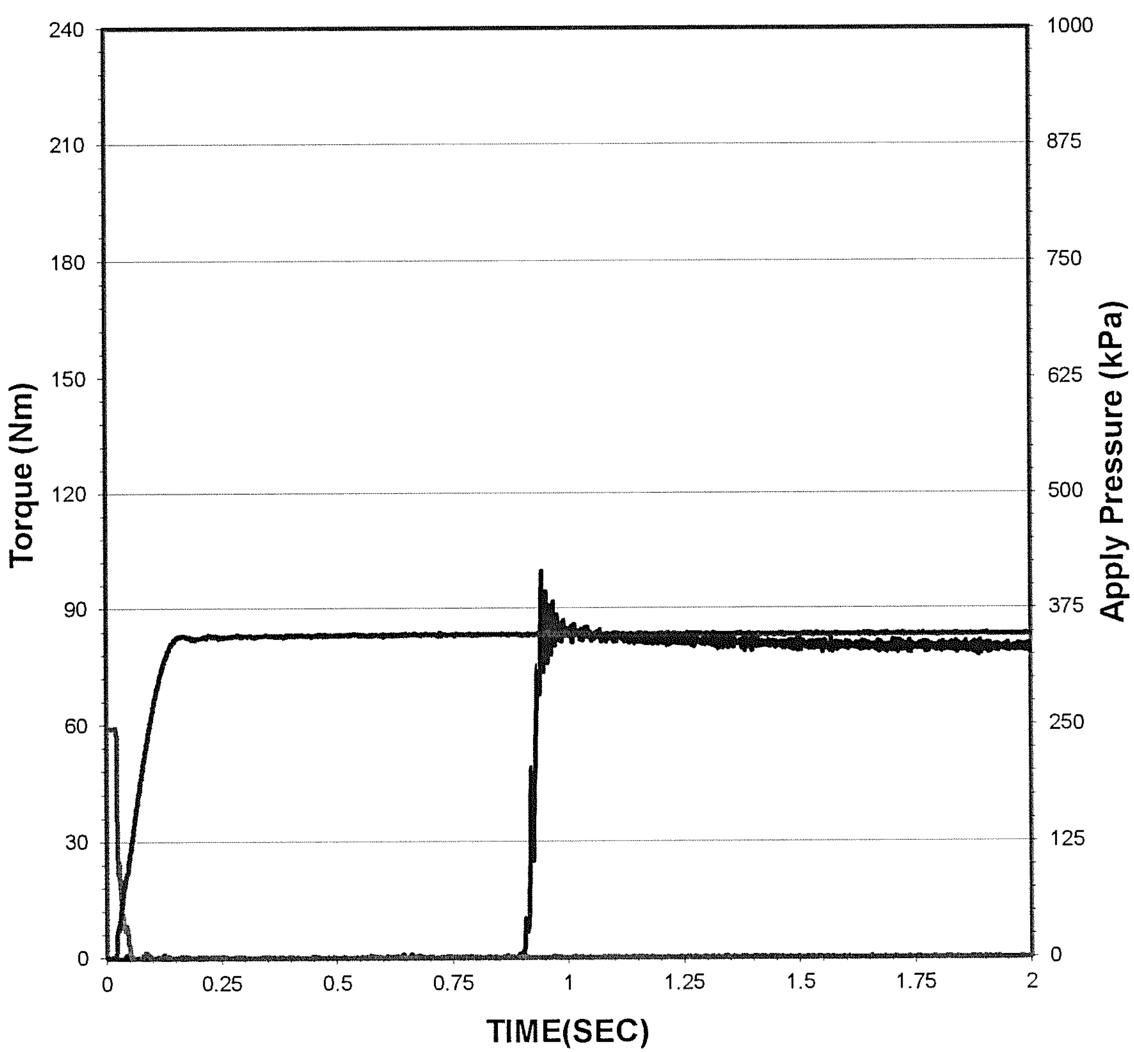
Apply Pressure:
At .25 Second: 346 kPa

Torque
Static Peak: 100 Nm
.25 Second: 93 Nm

Coefficient of Friction
Static Peak: 0.166
.25 Second: 0.154

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/9/2014

Time of Test: 21:36:15

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 500

PHASE A

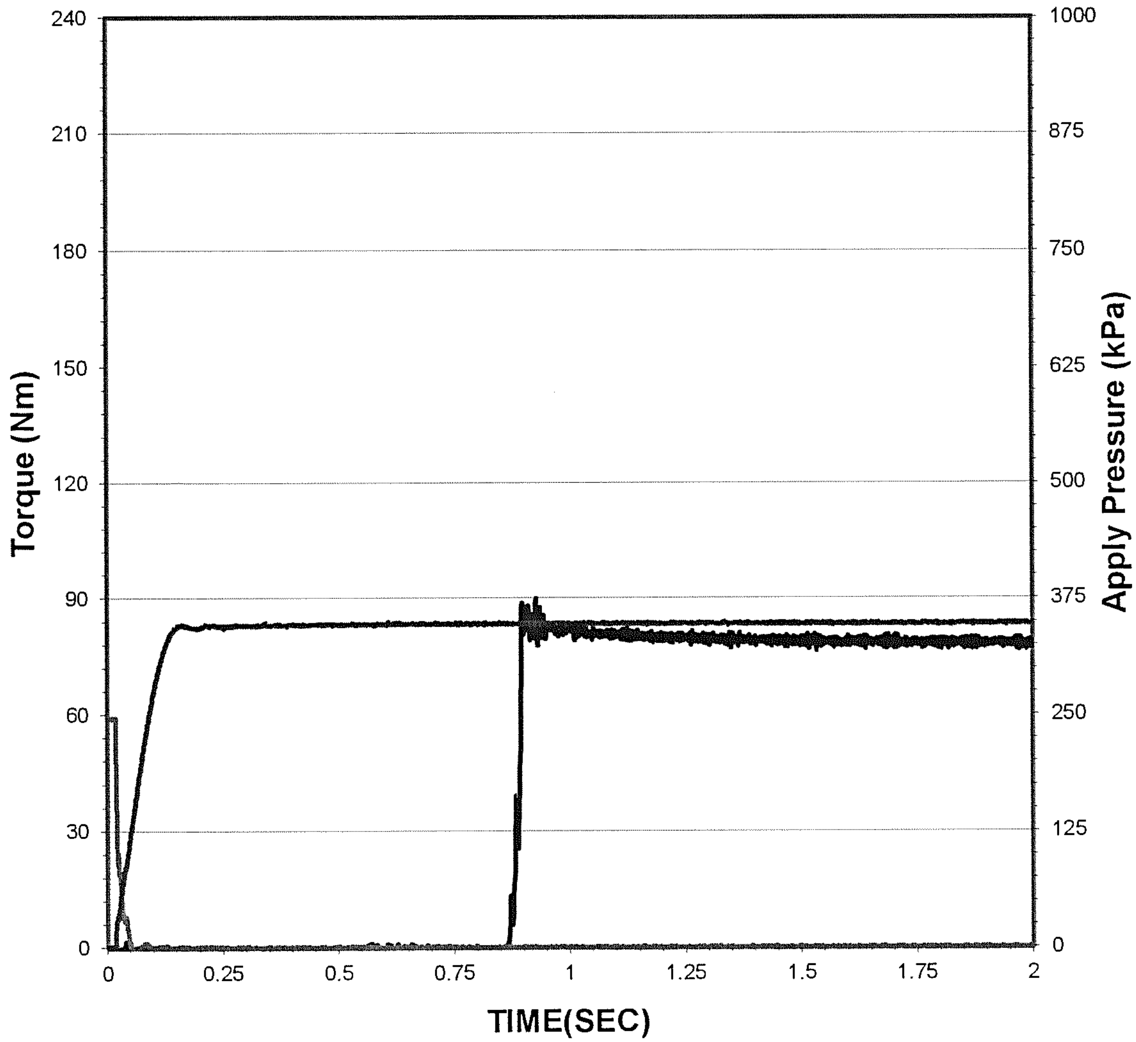
Apply Pressure:
At .25 Second: 347 kPa

Torque
Static Peak: 101 Nm
.25 Second: 82 Nm

Coefficient of Friction
Static Peak: 0.167
.25 Second: 0.136

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/9/2014

Time of Test: 23:41:27

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 1000

PHASE A

Apply Pressure:
At .25 Second: 347 kPa

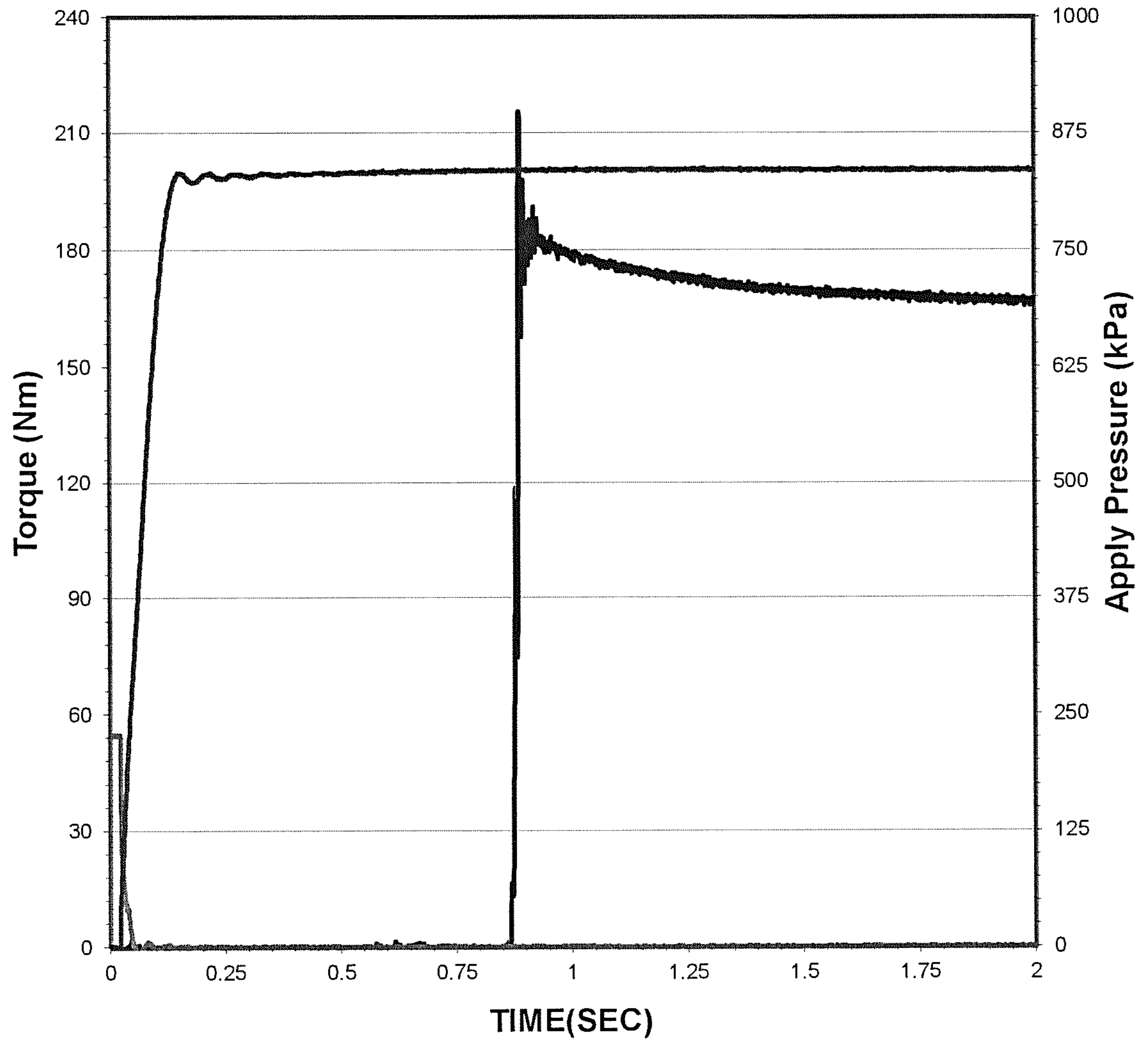
Torque
Static Peak: 91 Nm
.25 Second: 82 Nm

Coefficient of Friction
Static Peak: 0.151
.25 Second: 0.136

A-159

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 2:10:50

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 1500

PHASE B

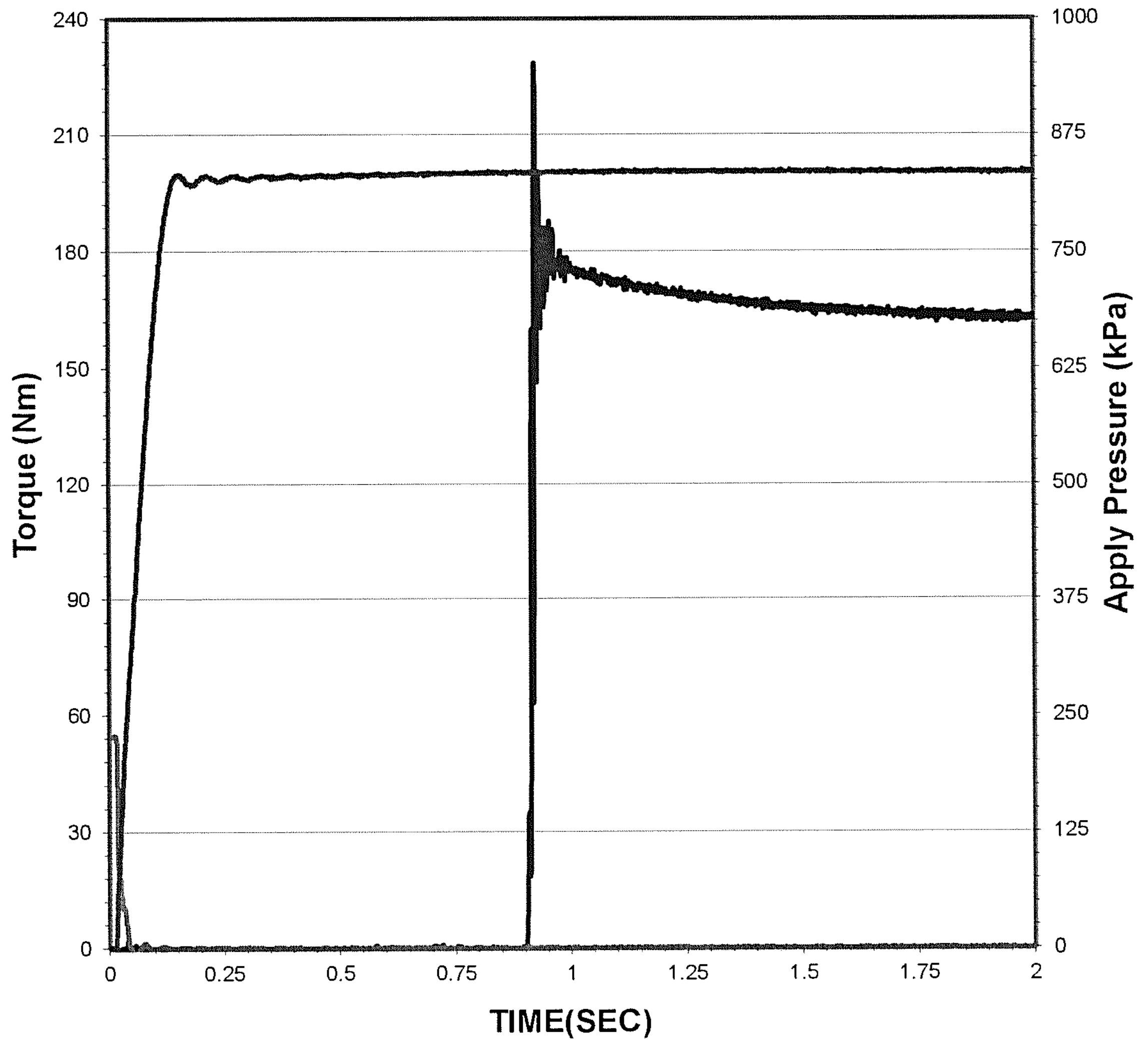
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 217 Nm
.25 Second: 177 Nm

Coefficient of Friction
Static Peak: 0.150
.25 Second: 0.122

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 4:16:02

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 2000

PHASE B

Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 229 Nm
.25 Second: 172 Nm

Coefficient of Friction
Static Peak: 0.159
.25 Second: 0.119

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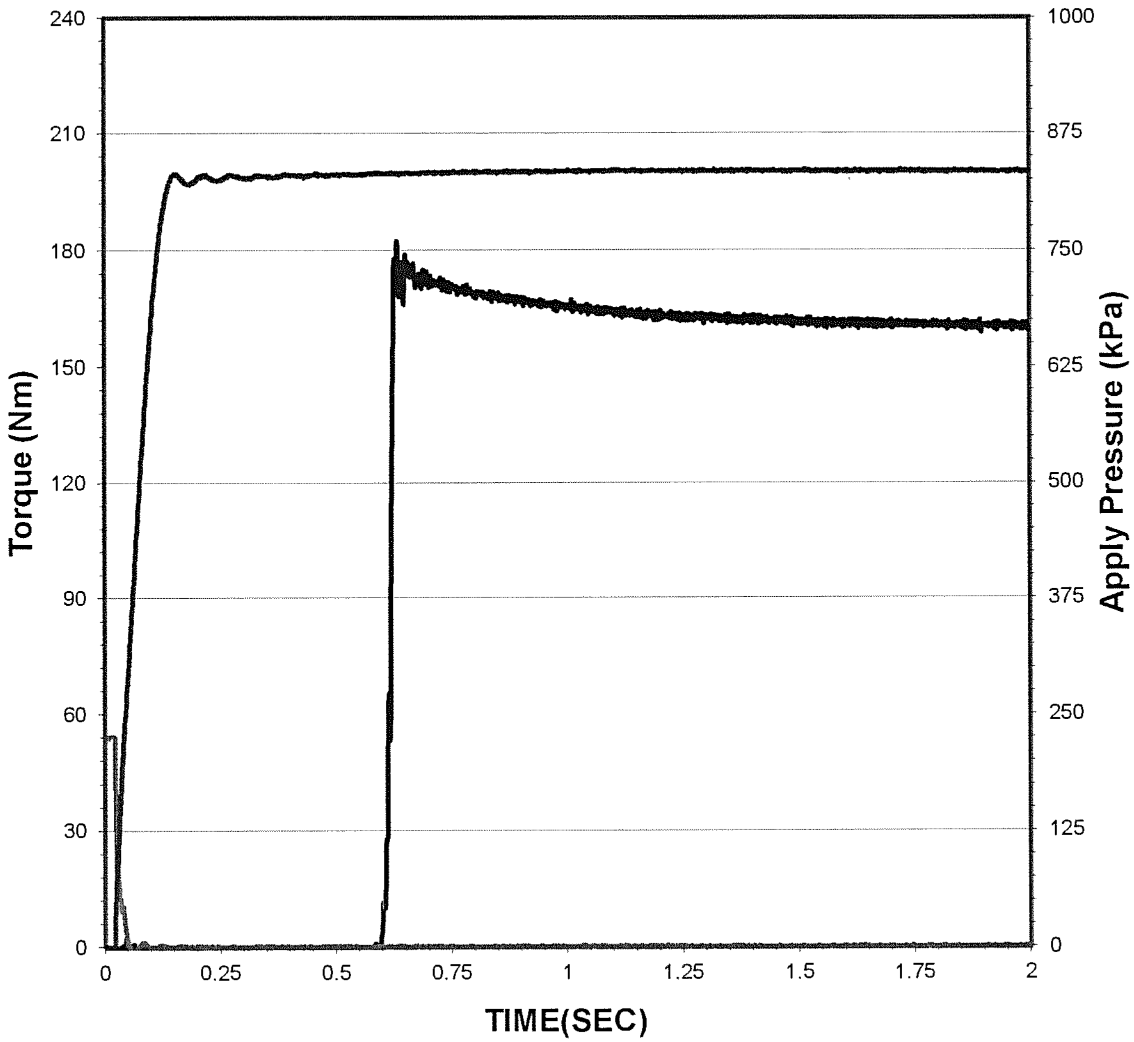
ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 6:21:14

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 2500

PHASE B

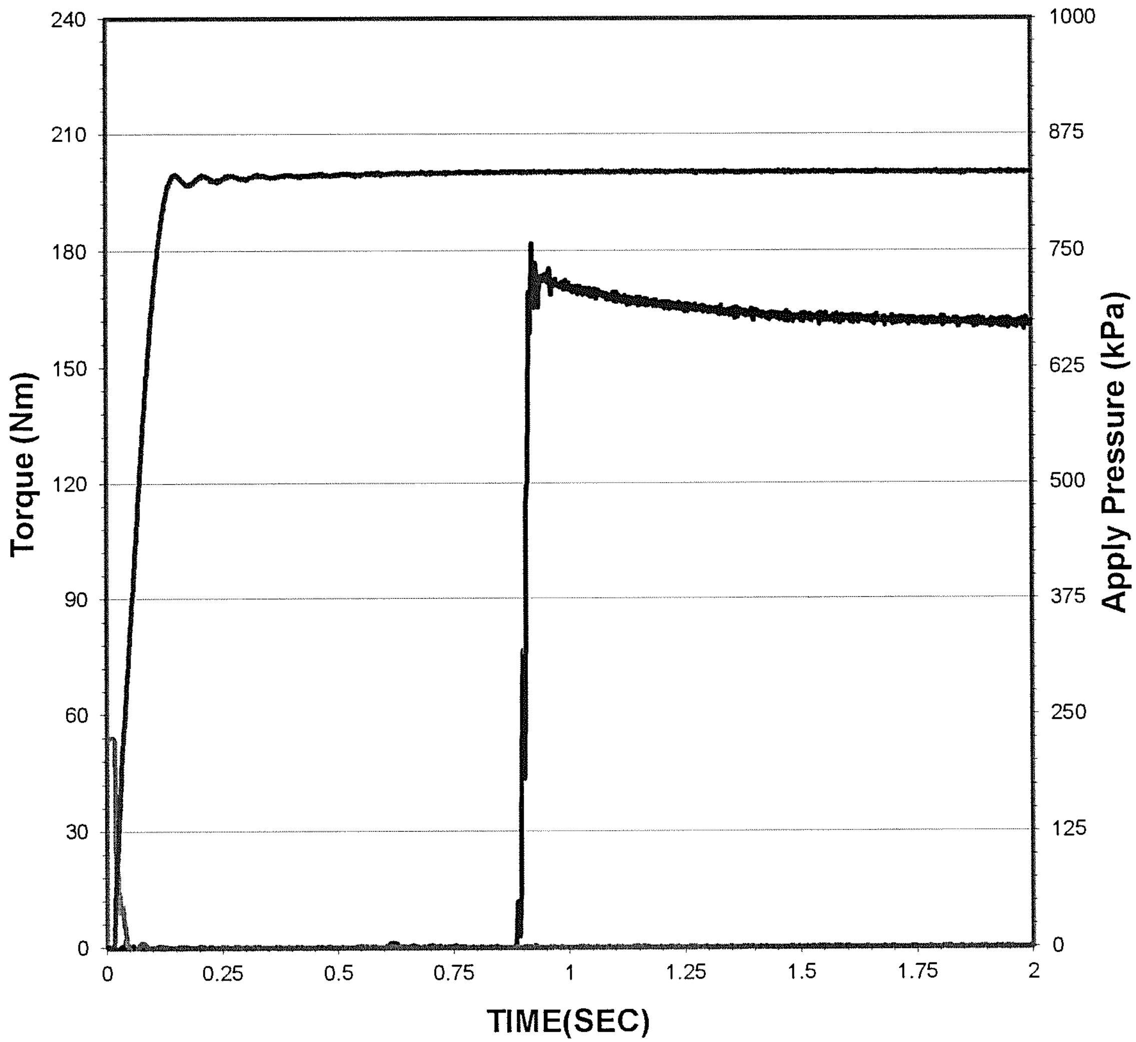
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 184 Nm
.25 Second: 170 Nm

Coefficient of Friction
Static Peak: 0.127
.25 Second: 0.117

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 8:26:26

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 3000

PHASE B

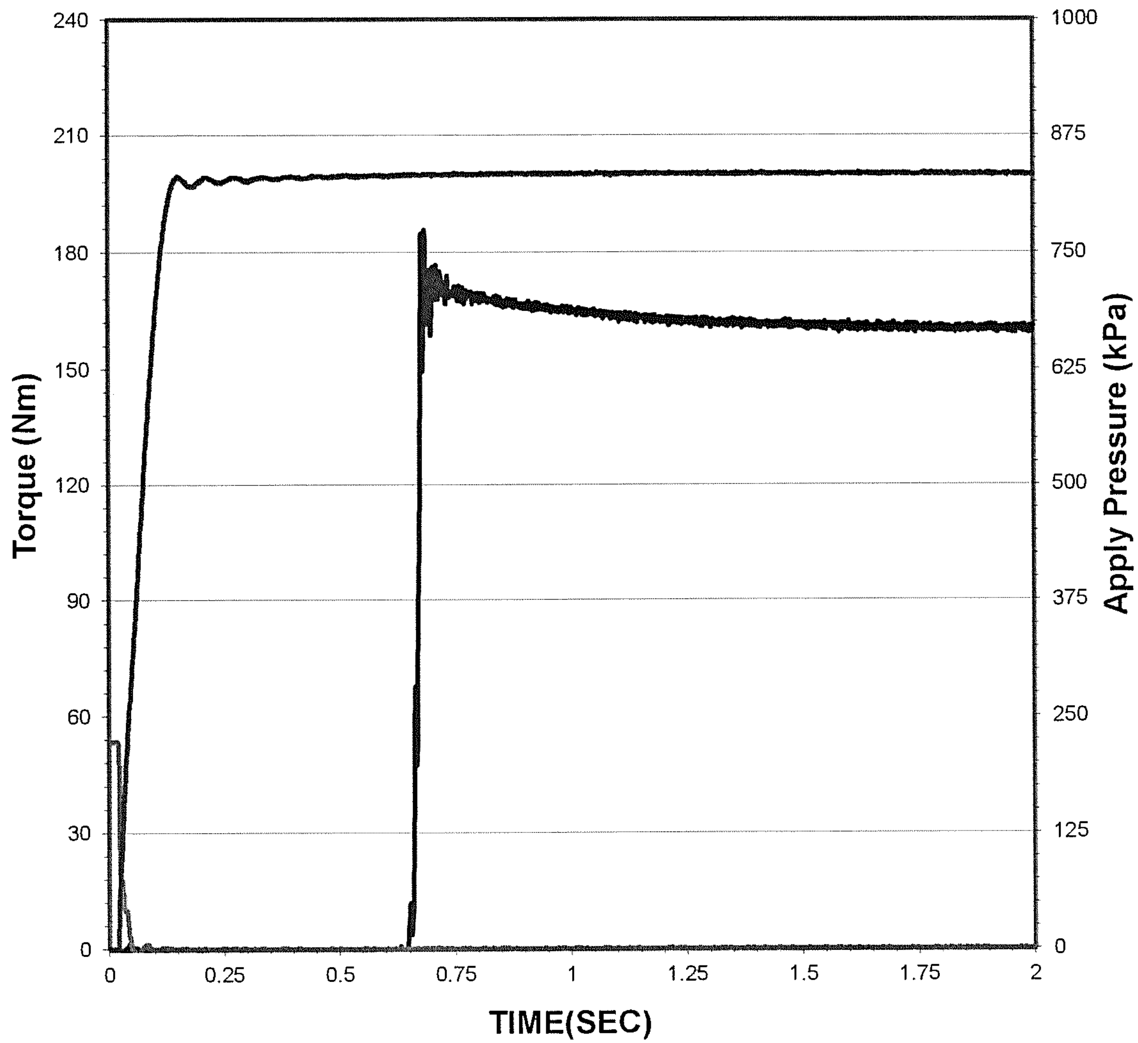
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 183 Nm
.25 Second: 168 Nm

Coefficient of Friction
Static Peak: 0.126
.25 Second: 0.116

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 10:31:38

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 3500

PHASE B

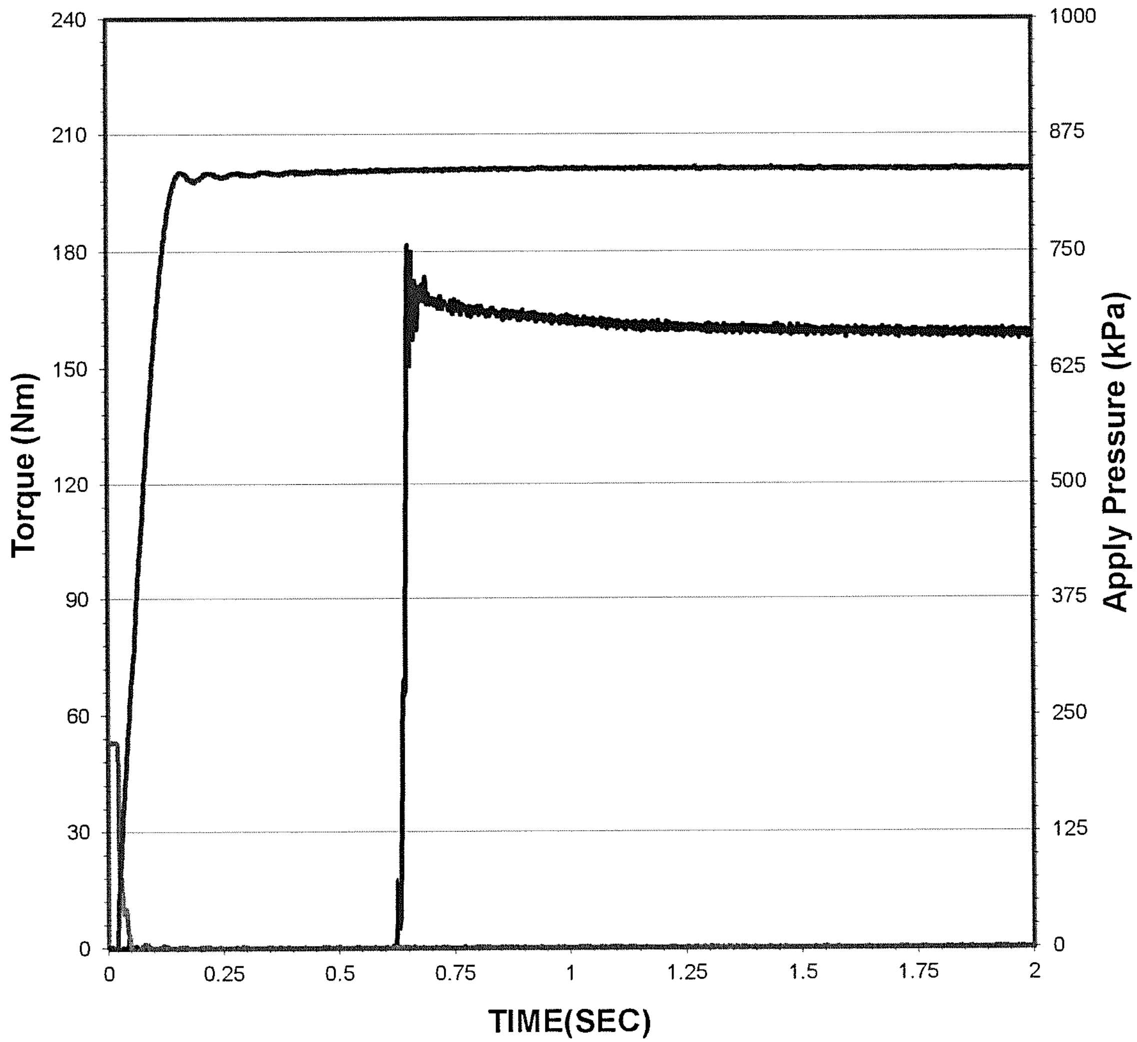
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 187 Nm
.25 Second: 167 Nm

Coefficient of Friction
Static Peak: 0.129
.25 Second: 0.116

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 12:36:49

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 4000

PHASE B

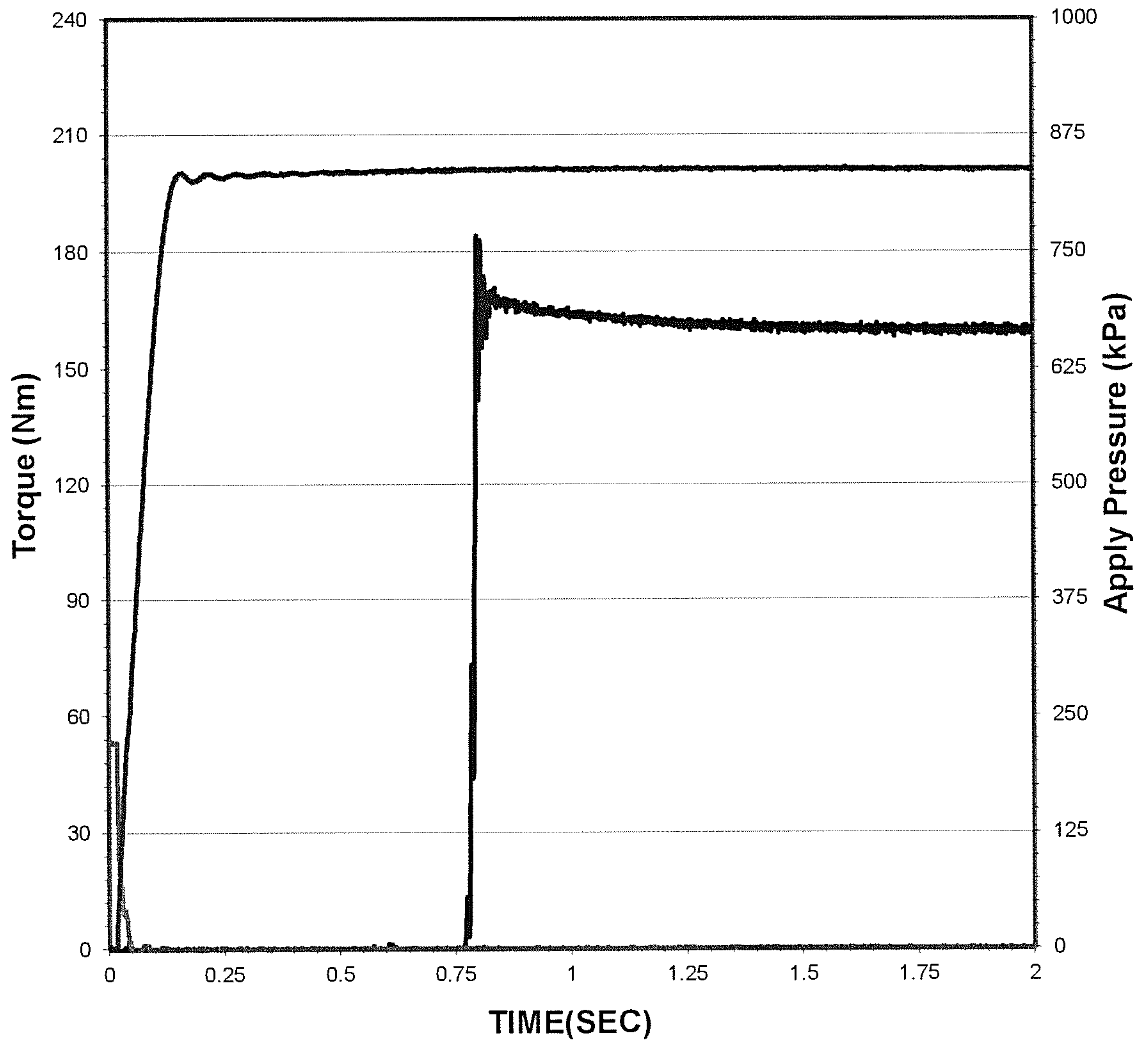
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 183 Nm
.25 Second: 164 Nm

Coefficient of Friction
Static Peak: 0.126
.25 Second: 0.113

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 14:42:01

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 4500

PHASE B

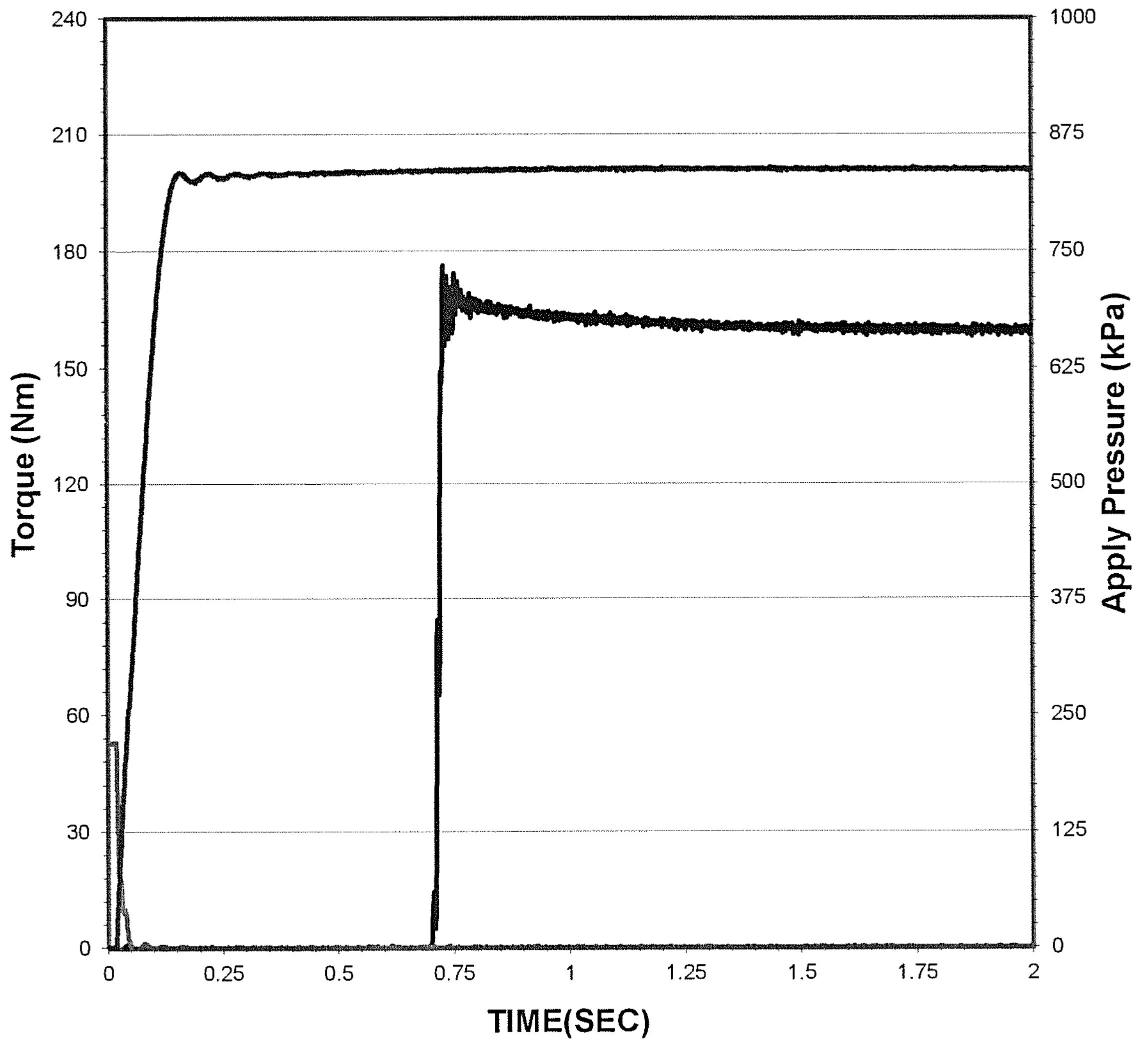
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 185 Nm
.25 Second: 165 Nm

Coefficient of Friction
Static Peak: 0.128
.25 Second: 0.114

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 16:47:13

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 5000

PHASE B

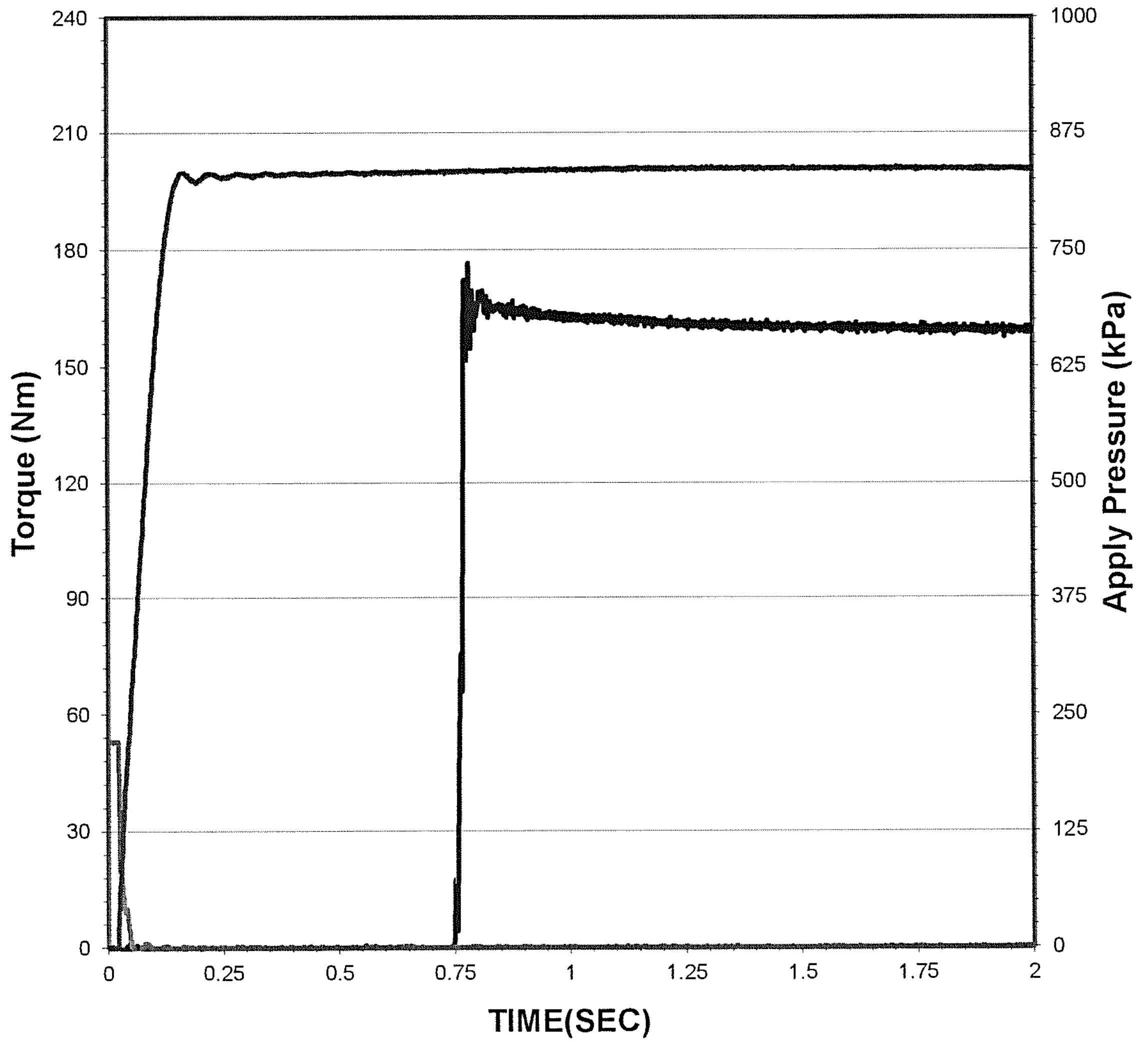
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 178 Nm
.25 Second: 166 Nm

Coefficient of Friction
Static Peak: 0.123
.25 Second: 0.114

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 3/10/2014

Time of Test: 18:52:25

Test Number: C4-8-1459

Fluid Code: LO306520

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 178 Nm
.25 Second: 165 Nm

Coefficient of Friction
Static Peak: 0.123
.25 Second: 0.114

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

This page has been AMENDED.
Initial: CR
Date: 3/21/14

Report on

ALLISON TRANSMISSION FLUID
TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO306520

Test Number:
C2-8-1616

March 9, 2014

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory: SWRI
Test Number: C2-8-1616
Friction Plate Batch: LOT 6
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-306520
Sponsor Fluid Code: LO306520
Completion Date: 03/09/14

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0860	0.0758

	Before	After
Pack Clearance	0.9652	1.2446

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1581	06/04/12	TRANSYND RD 07-27-11
C2-0-1592	01/04/13	RDL-2746 08-12
C2-0-1608	10/10/13	RDL-2746 08-12

	New	EOT
Viscosity at 40°C, cSt	47.68	40.86
Viscosity at 100°C, cSt	8.91	7.76
Iron Content, ppm	2	198

D5185	New Fluid (ppm)
Ba	<1
B	2
Ca	3605
Mg	11
P	1391
Si	6
Na	18
Zn	1684

Name: Matthew Jackson
Title: Manager

Signature:
Date: 3/21/14

ALLISON C- 4 PAPER FRICTION TEST
(Torque in N*m)

Sponsor Fluid Code:	**LO306520**	Test Number:	**C2-8-1616**
Lab Fluid Code:	**LO-306520**	Fric. Plate Batch:	**LOT 6**
Completion Date:	**03/09/2014**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.52	194	242	48	243	240
500	0.56	176	296	120	310	300
1000	0.50	197	316	119	340	324
2500	0.47	213	307	94	326	313
5000	0.47	221	291	70	323	301
7500	0.47	219	276	57	282	280
10000	0.46	226	272	46	277	276

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.52	0.094	0.118	0.024	0.118	0.117
500	0.56	0.086	0.144	0.058	0.151	0.146
1000	0.50	0.096	0.154	0.058	0.166	0.158
2500	0.47	0.104	0.150	0.046	0.159	0.152
5000	0.47	0.108	0.142	0.034	0.157	0.147
7500	0.47	0.107	0.134	0.027	0.137	0.136
10000	0.46	0.110	0.132	0.022	0.135	0.134

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.520	0.460	-11.54	**P**
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.094	0.110	17.02	**F**
Static Friction Coeff.	N/A	N/A	0.118	0.132	11.86	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.118	0.135	14.41	
0.25 Second Low Speed Coeff.	N/A	N/A	0.117	0.134	14.53	

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ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO306520	**Test Number : C2-8-1616**	**Completion Date : 3/9/2014**
Lab Fluid Code: LO-306520	**Steel Plate Batch: 10/09/2008**	**Fric Plate Batch : LOT 6**

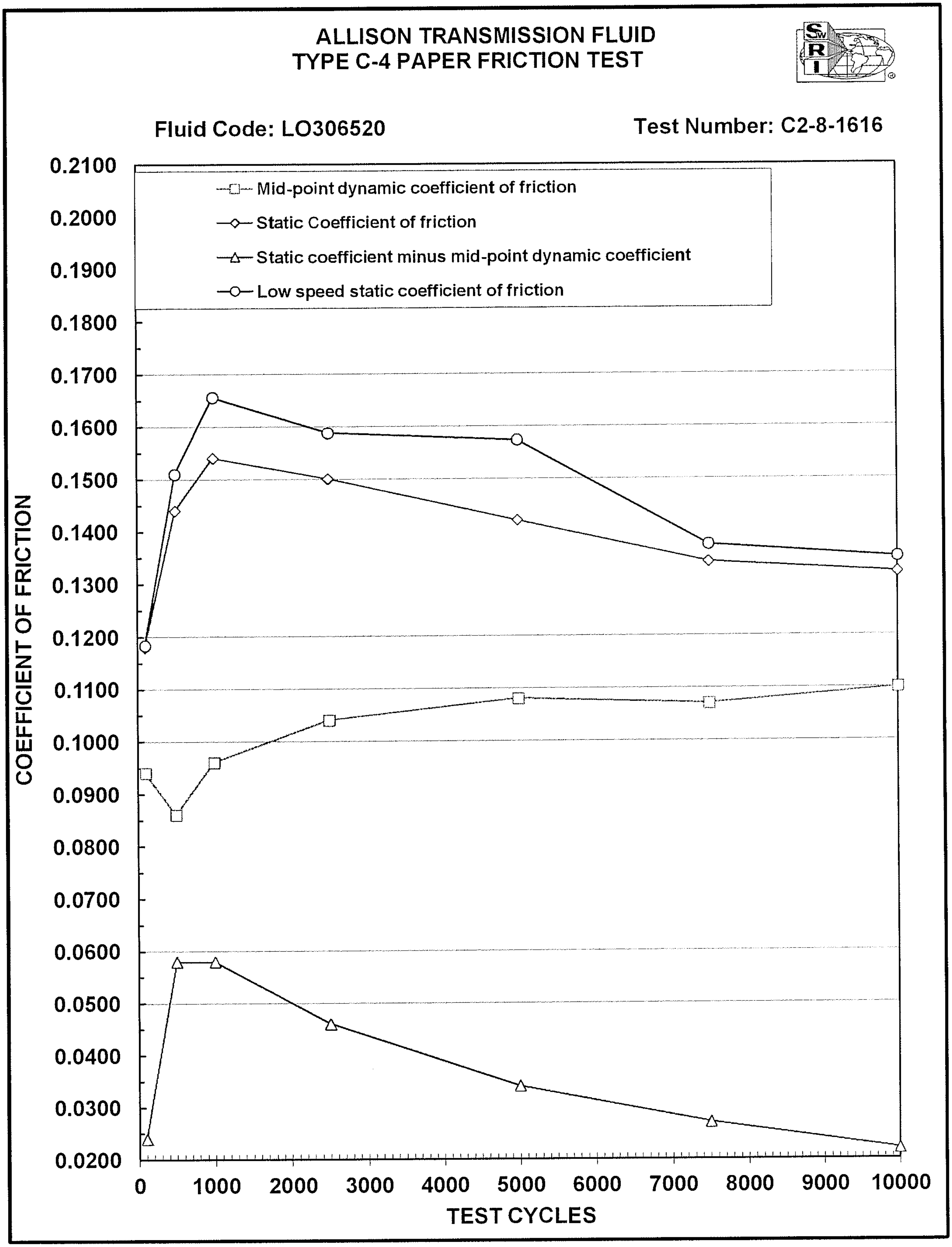
Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0440	1.9590	2.0370	1.9580	0.0850		0.0790
	120	2.0440	1.9580	2.0230	1.9450	0.0860		0.0780
	240	2.0450	1.9640	2.0380	1.9590	0.0810		0.0790
	Average					0.0840	0.0814	0.0787
5	Top	2.0430	1.9610	2.0330	1.9670	0.0820		0.0660
	120	2.0470	1.9740	2.0470	1.9850	0.0730		0.0620
	240	2.0410	1.9630	2.0310	1.9710	0.0780		0.0600
	Average					0.0777	0.0702	0.0627
STEELS SEPARATORS								
1	Top	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	120	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	240	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7460	1.7460	1.7460	1.7460	0.0000		0.0000
	120	1.7460	1.7460	1.7460	1.7460	0.0000		0.0000
	240	1.7460	1.7460	1.7470	1.7470	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
4	Top	1.7470	1.7470	1.7460	1.7460	0.0000		0.0000
	120	1.7470	1.7470	1.7460	1.7460	0.0000		0.0000
	240	1.7460	1.7460	1.7460	1.7460	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	120	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	240	1.7510	1.7510	1.7510	1.7510	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION
(Anything Unusual)

Test Date and Operator's Name: 3/7/2014 JGUERRERO

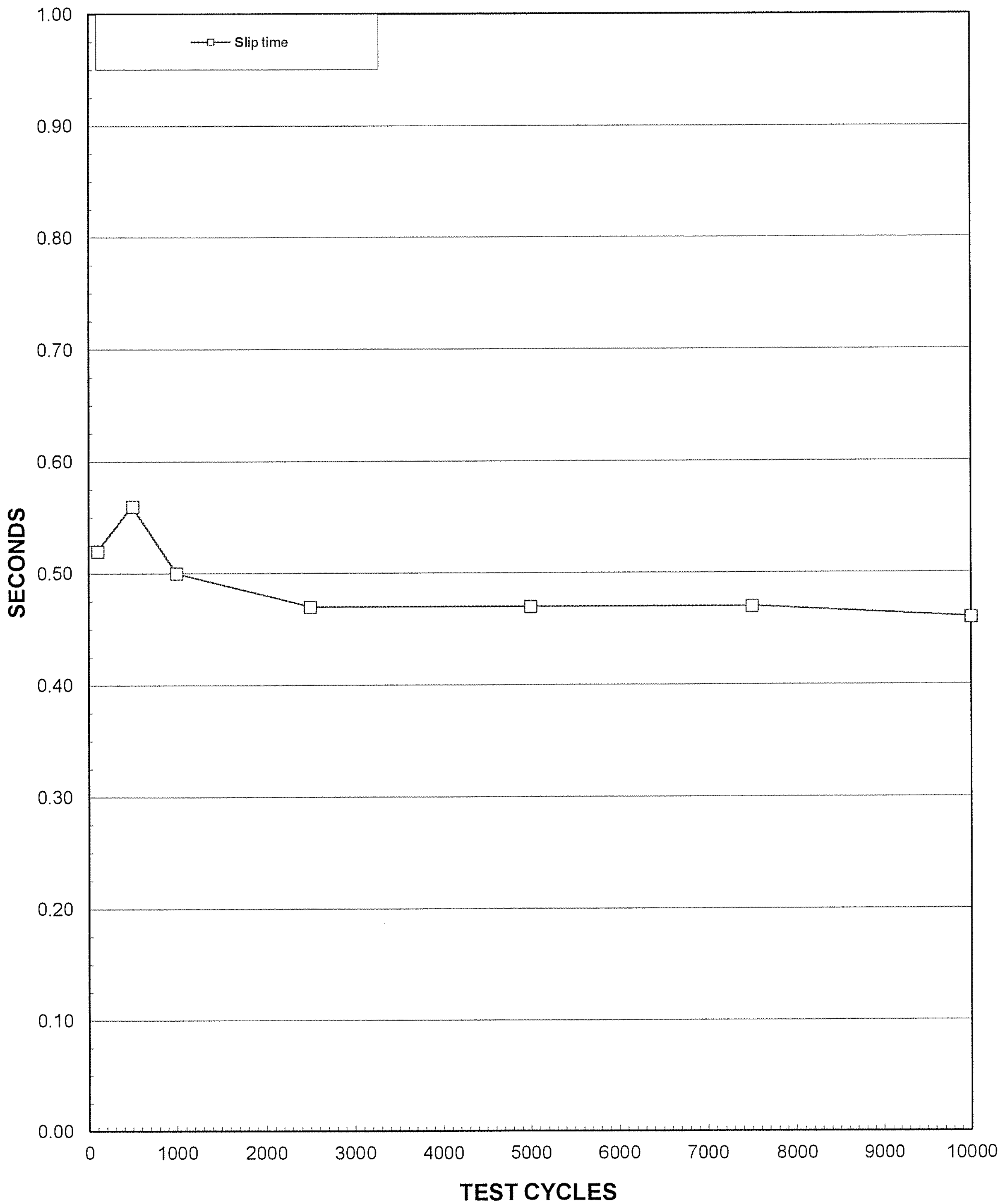
Reviewed By (Signature and Date) 3/21/14

Pack ID#: 5152


ALLISON TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO306520
Test Number: C2-8-1616
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

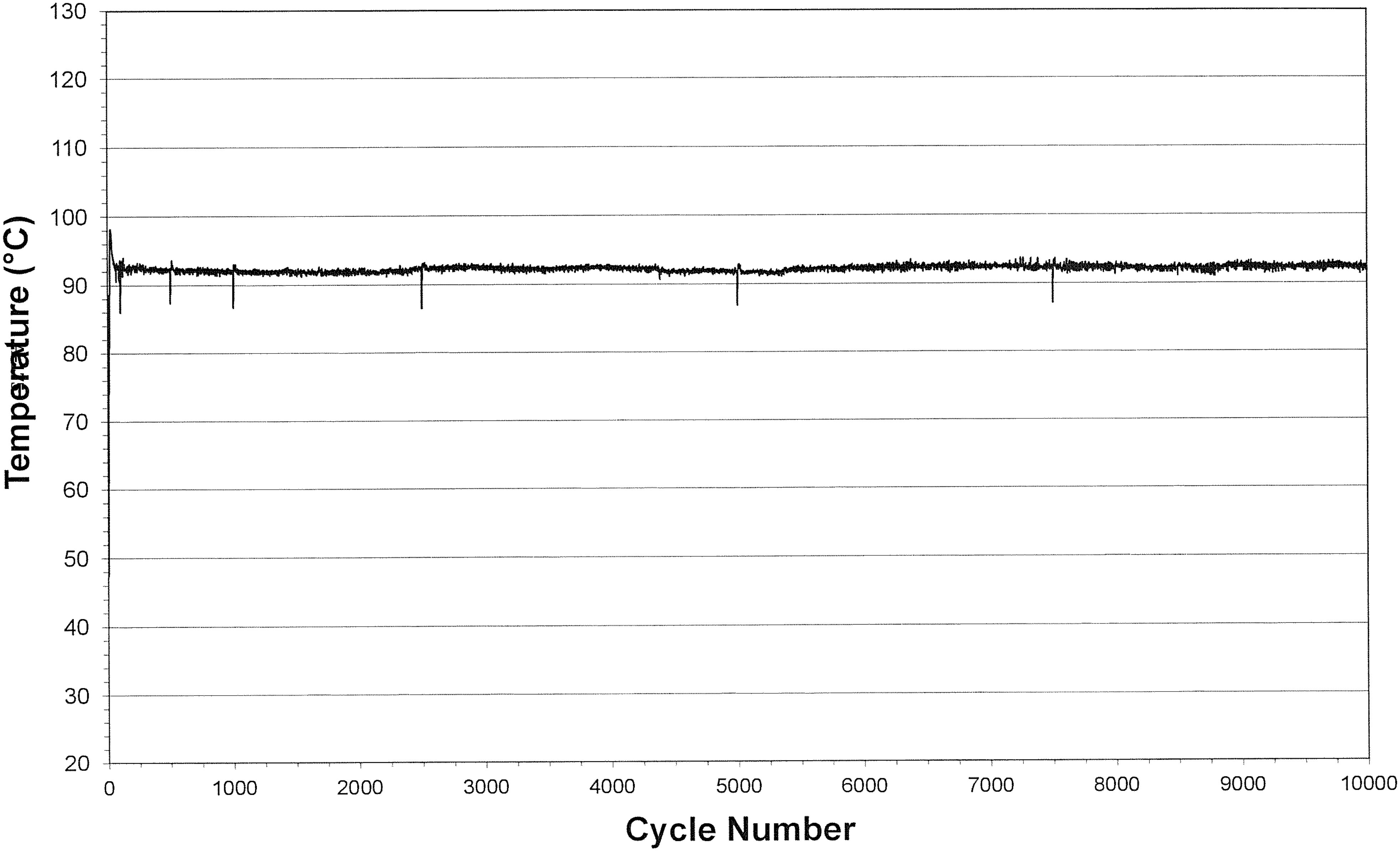
ALLISON TRANSMISSION FLUID TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO306520 **Test Number: C2-8-1616**



C2-8-1616 LO306520

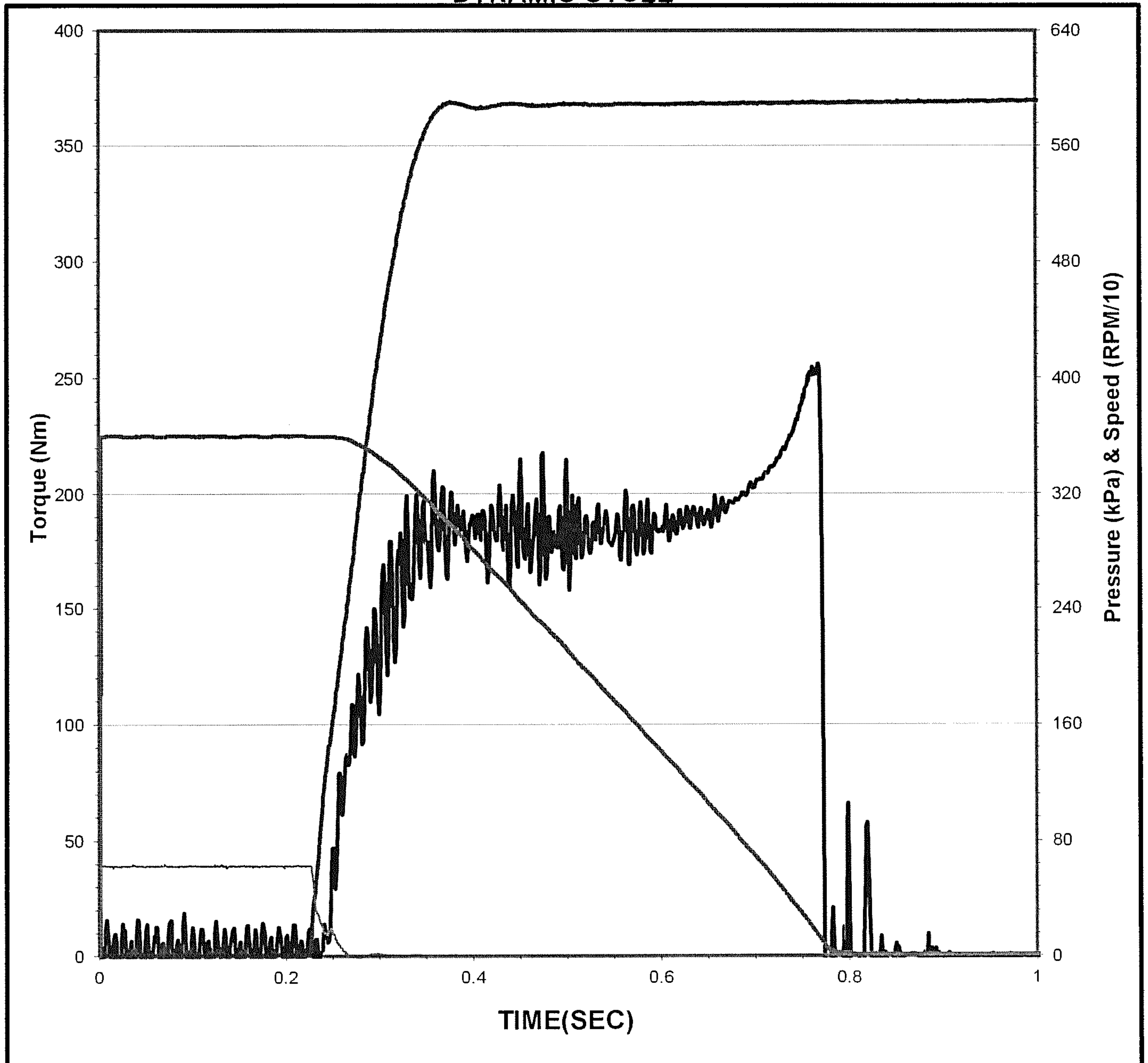
Temp: Max=98.2°C Min=47.4°C Avg=92.1°C



DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	9:12:37
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	10
Temperature:	79.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.546 Sec

Torque

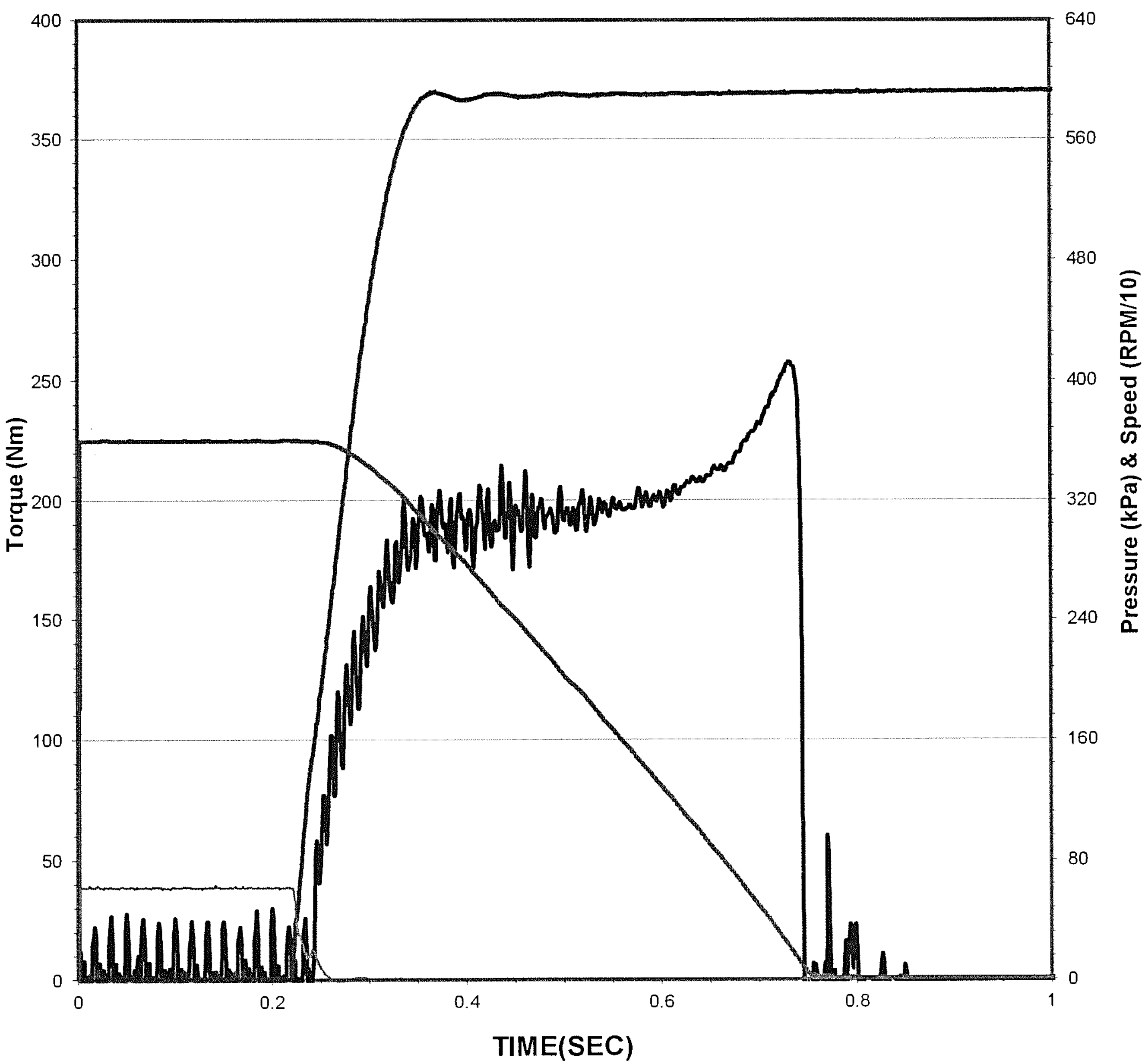
0.2 Sec Dyn:	187 N*m
Midpoint Dyn:	183 N*m
LwSpd Dynamic:	255 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.124

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	9:35:08
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	99
Temperature:	91.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.524 Sec

Torque

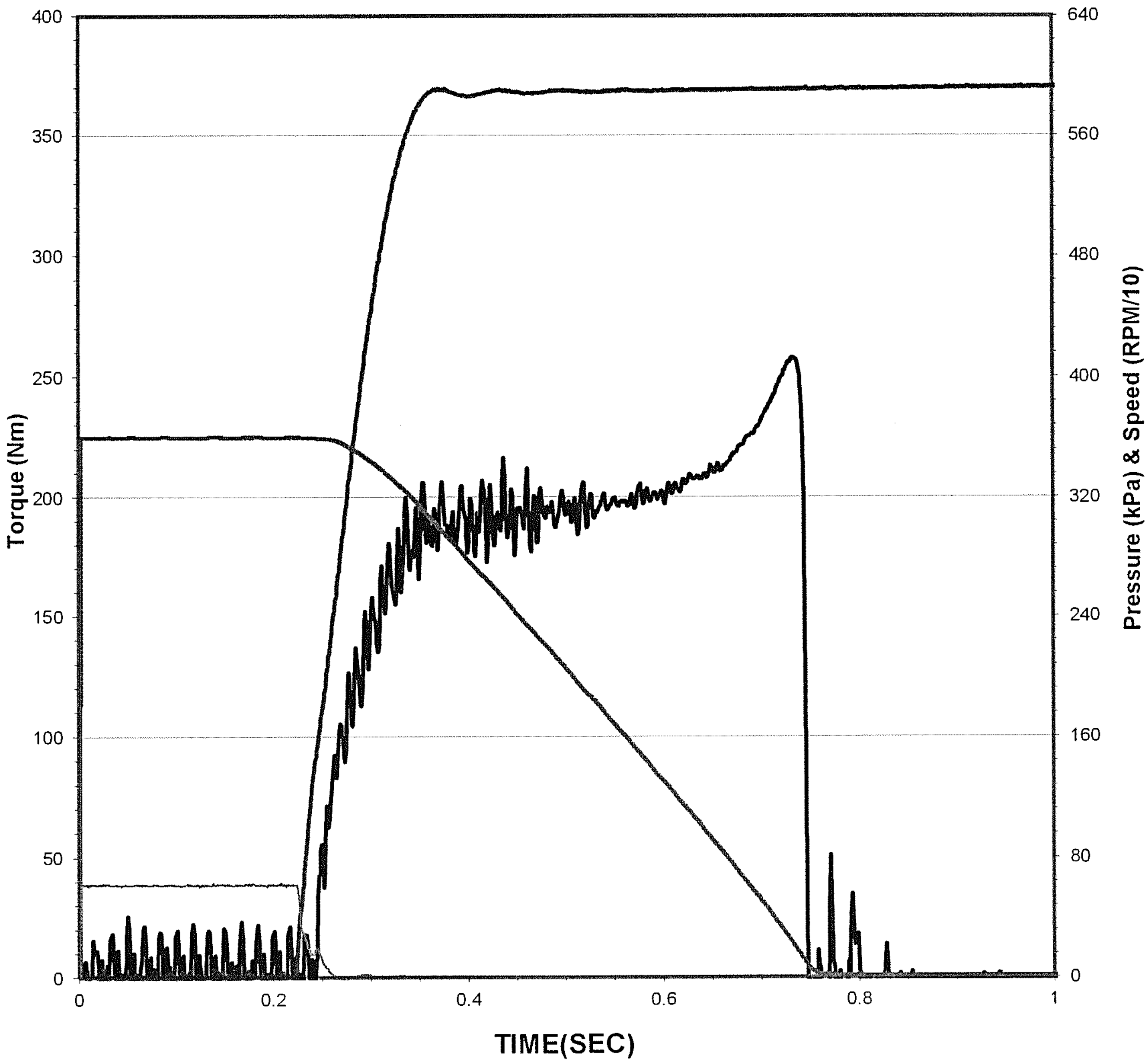
0.2 Sec Dyn:	192 N*m
Midpoint Dyn:	195 N*m
LwSpd Dynamic:	243 N*m

Coefficient of Friction

.2 Sec Dyn:	0.094
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.119

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	9:35:23
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	100
Temperature:	91.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.522 Sec

Torque

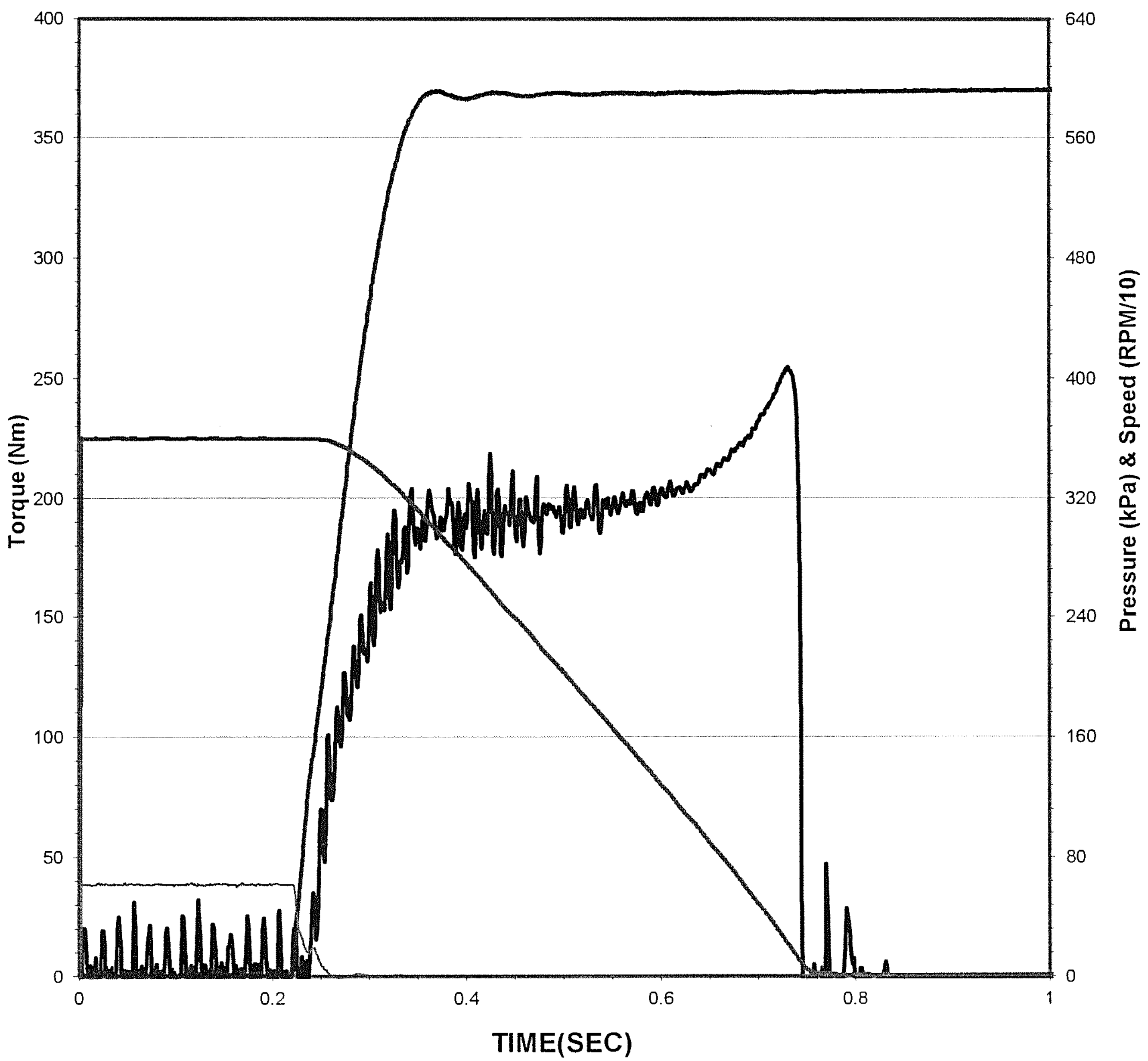
0.2 Sec Dyn:	189 N*m
Midpoint Dyn:	194 N*m
LwSpd Dynamic:	239 N*m

Coefficient of Friction

.2 Sec Dyn:	0.092
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.117

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	9:35:54
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	101
Temperature:	85.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.524 Sec

Torque

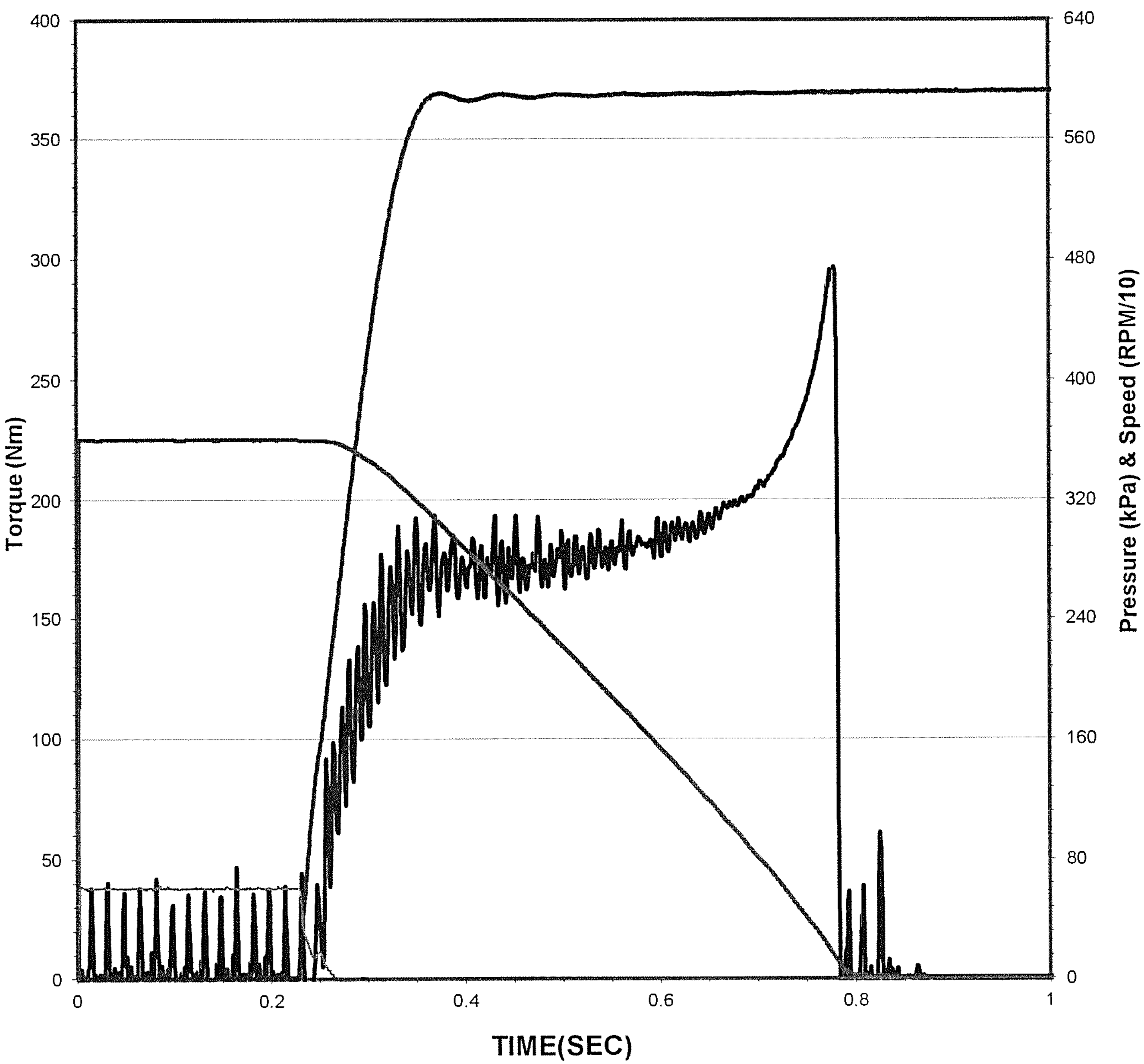
0.2 Sec Dyn:	192 N*m
Midpoint Dyn:	194 N*m
LwSpd Dynamic:	243 N*m

Coefficient of Friction

.2 Sec Dyn:	0.094
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.119

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	11:15:24
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	499
Temperature:	91.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.555 Sec

Torque

0.2 Sec Dyn:	175 N*m
Midpoint Dyn:	176 N*m
LwSpd Dynamic:	296 N*m

Coefficient of Friction

.2 Sec Dyn:	0.085
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.144

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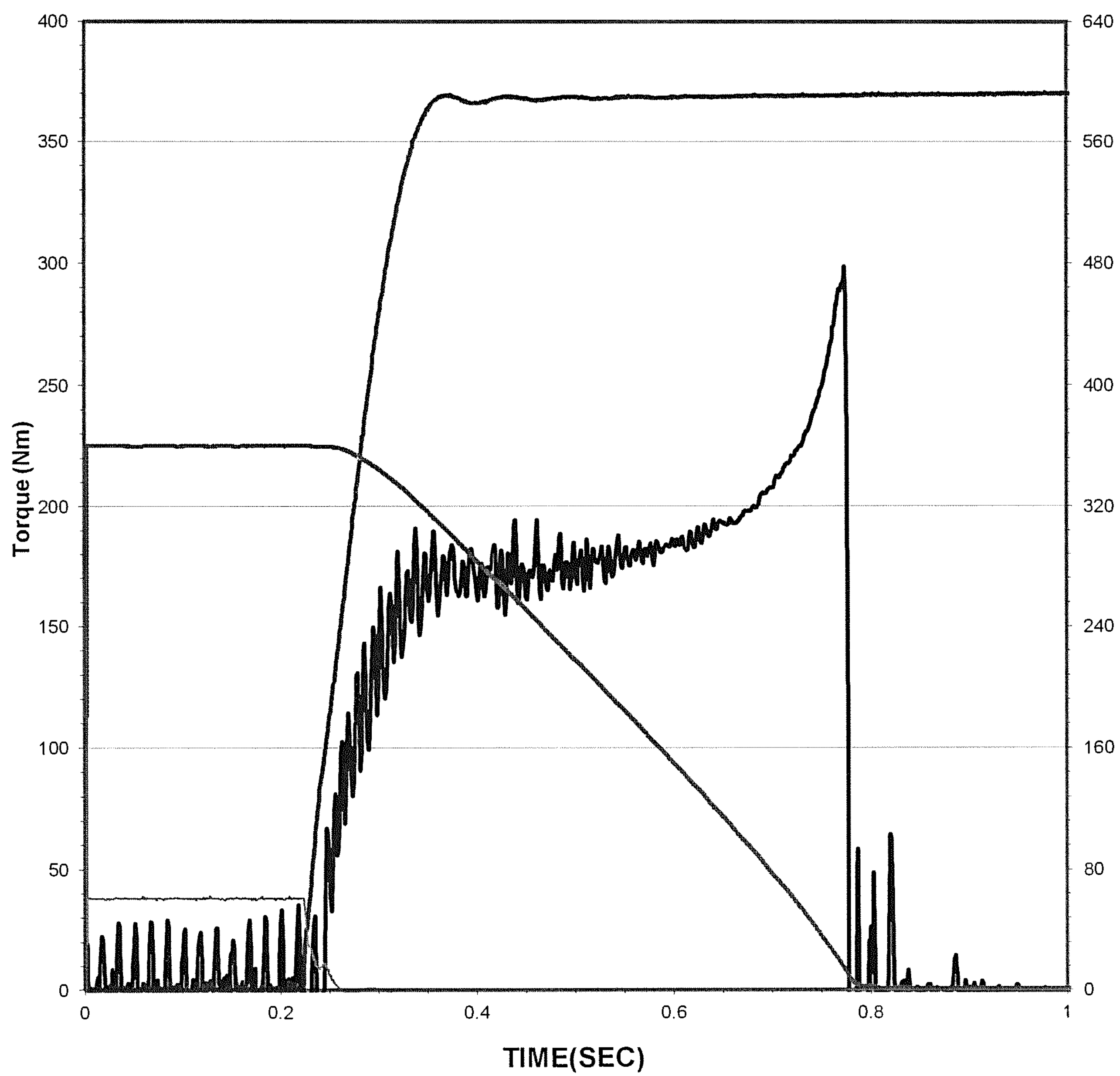
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	11:15:40
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	500
Temperature:	92.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.554 Sec

Torque

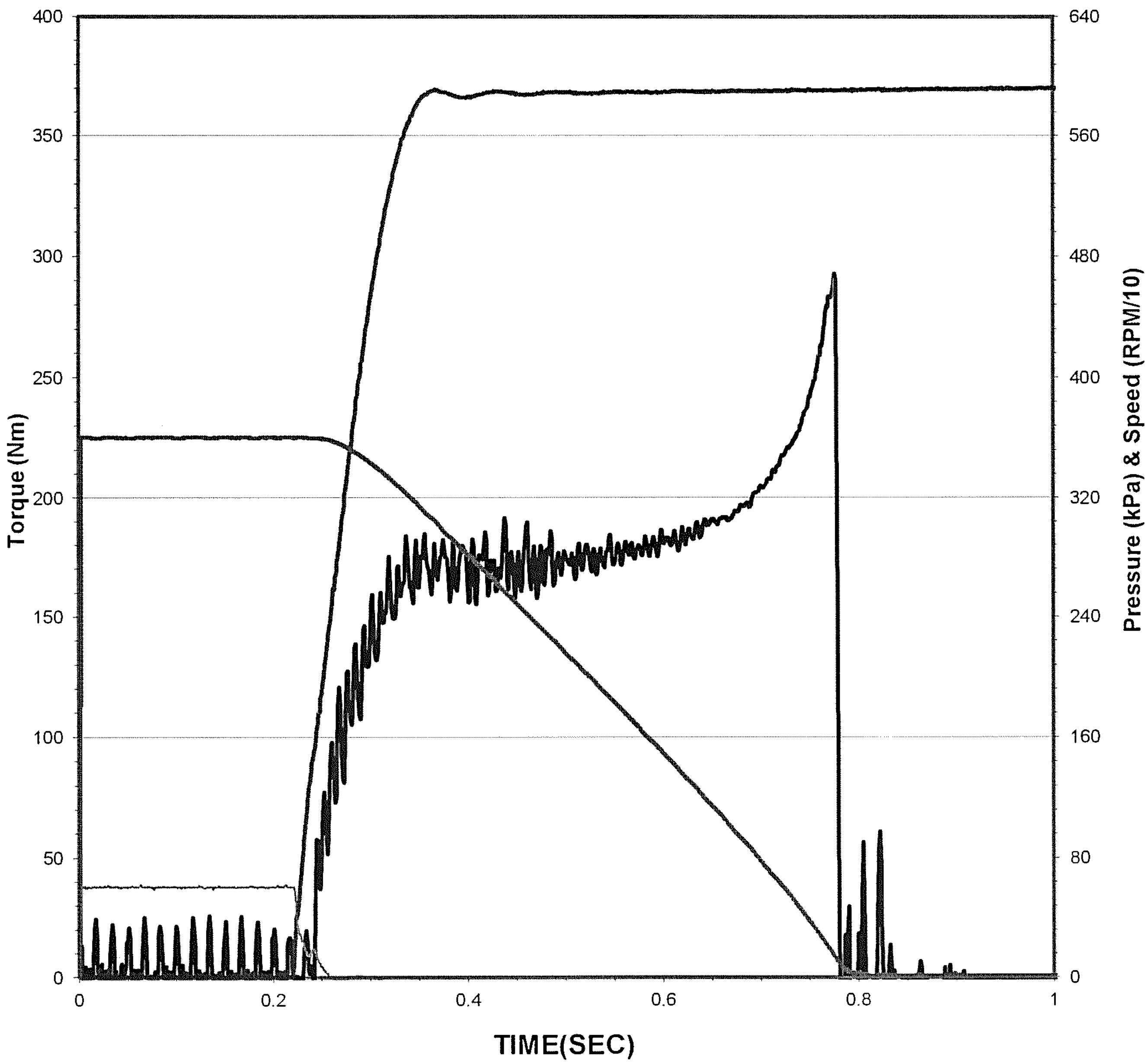
0.2 Sec Dyn:	173 N*m
Midpoint Dyn:	176 N*m
LwSpd Dynamic:	300 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.146

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	11:16:11
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	501
Temperature:	**87.3 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.7 ± 0.40 KJ)
Engage Time:	0.559 Sec

Torque

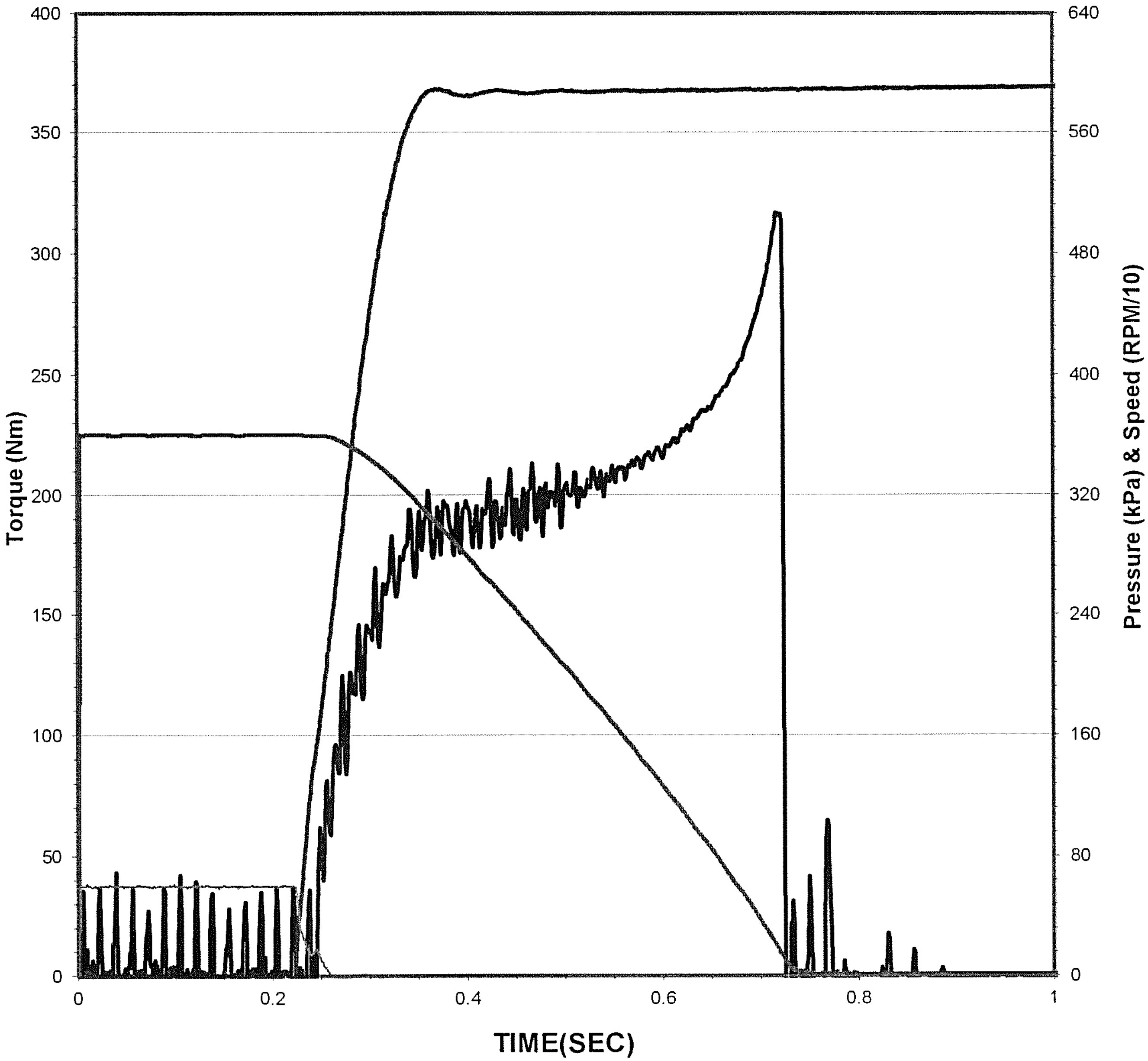
0.2 Sec Dyn:	172 N*m
Midpoint Dyn:	175 N*m
LwSpd Dynamic:	292 N*m

Coefficient of Friction

.2 Sec Dyn:	0.084
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.142

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	13:20:41
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	999
Temperature:	92.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.5 Sec

Torque

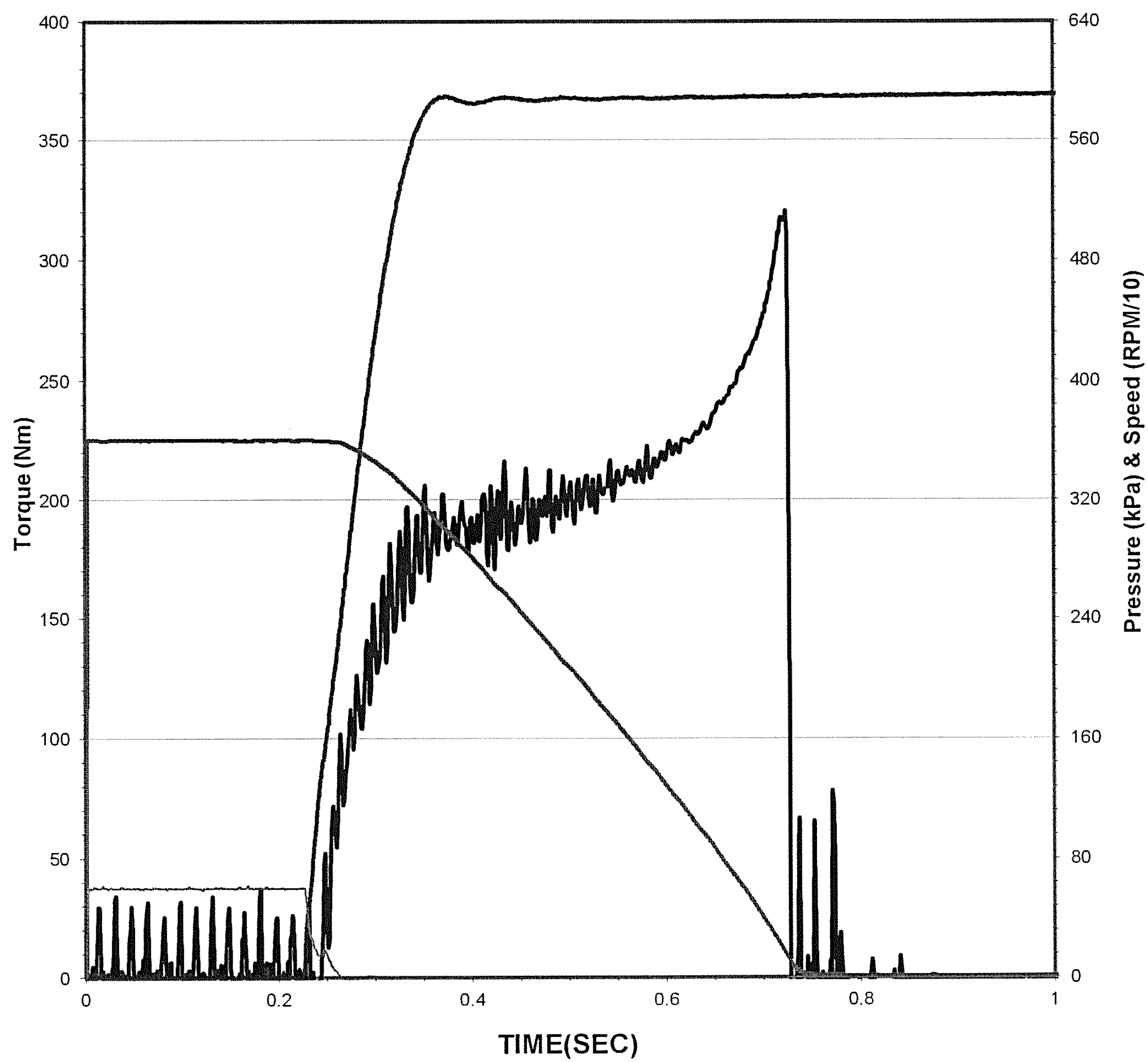
0.2 Sec Dyn:	194 N*m
Midpoint Dyn:	198 N*m
LwSpd Dynamic:	315 N*m

Coefficient of Friction

.2 Sec Dyn:	0.094
Midpoint Dyn:	0.096
LwSpd Dynamic:	0.154

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	13:20:56
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	1000
Temperature:	92.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.5 Sec

Torque

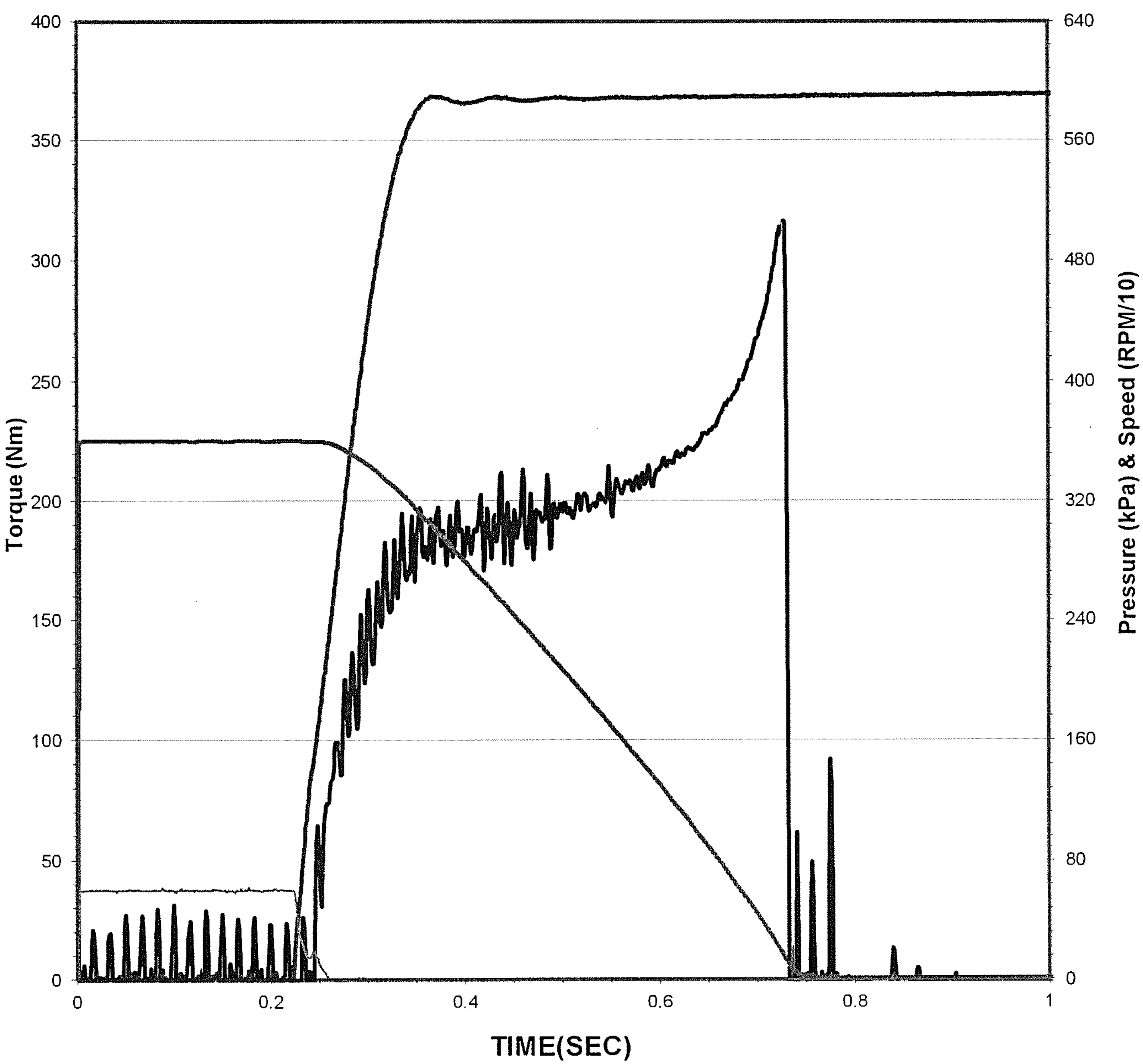
0.2 Sec Dyn:	194 N*m
Midpoint Dyn:	199 N*m
LwSpd Dynamic:	314 N*m

Coefficient of Friction

.2 Sec Dyn:	0.094
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.153

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	13:21:27
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	1001
Temperature:	86.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.508 Sec

Torque

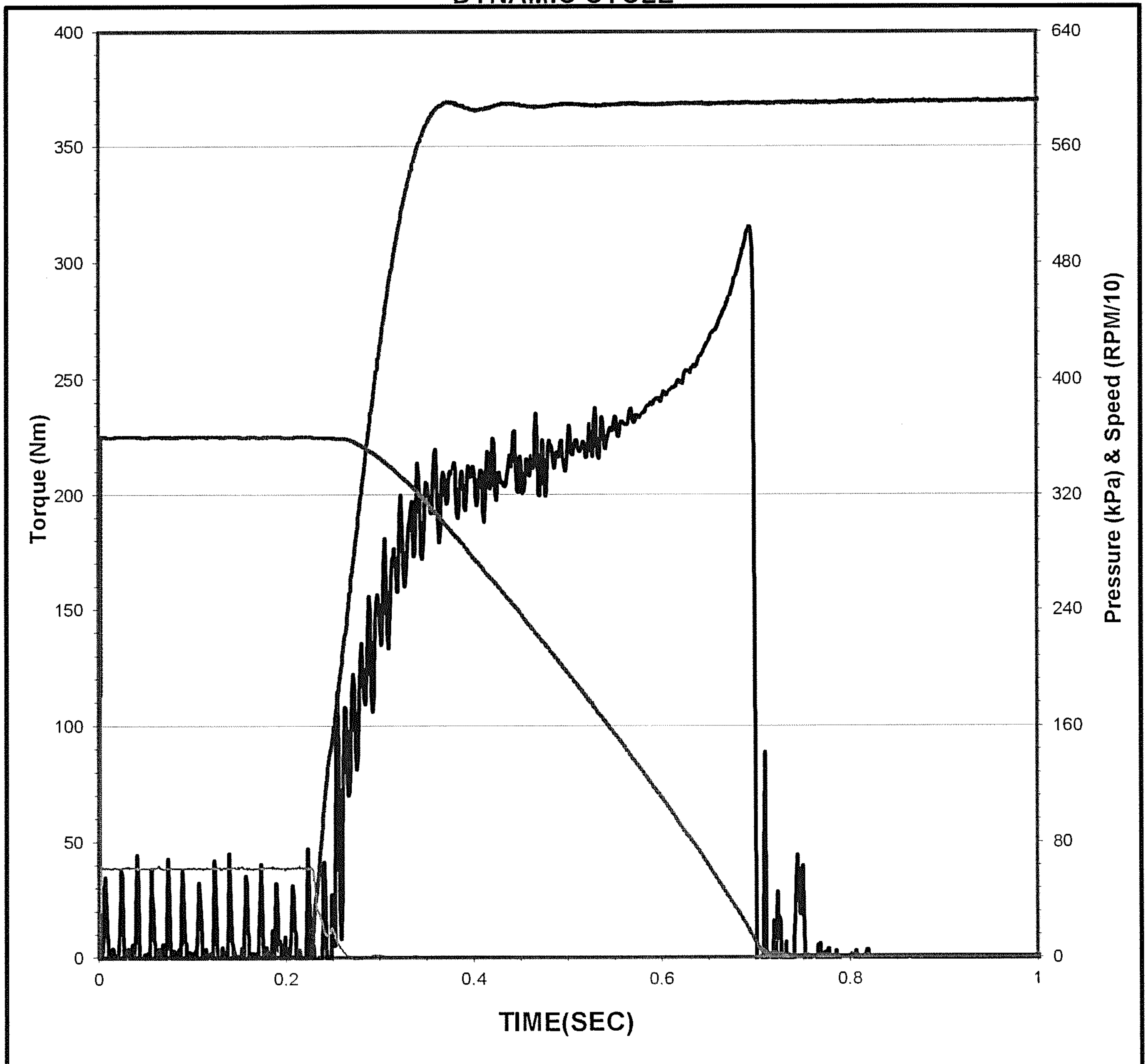
0.2 Sec Dyn:	187 N*m
Midpoint Dyn:	195 N*m
LwSpd Dynamic:	318 N*m

Coefficient of Friction

.2 Sec Dyn:	0.091
Midpoint Dyn:	0.095
LwSpd Dynamic:	0.155

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	19:35:57
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	2499
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.472 Sec

Torque

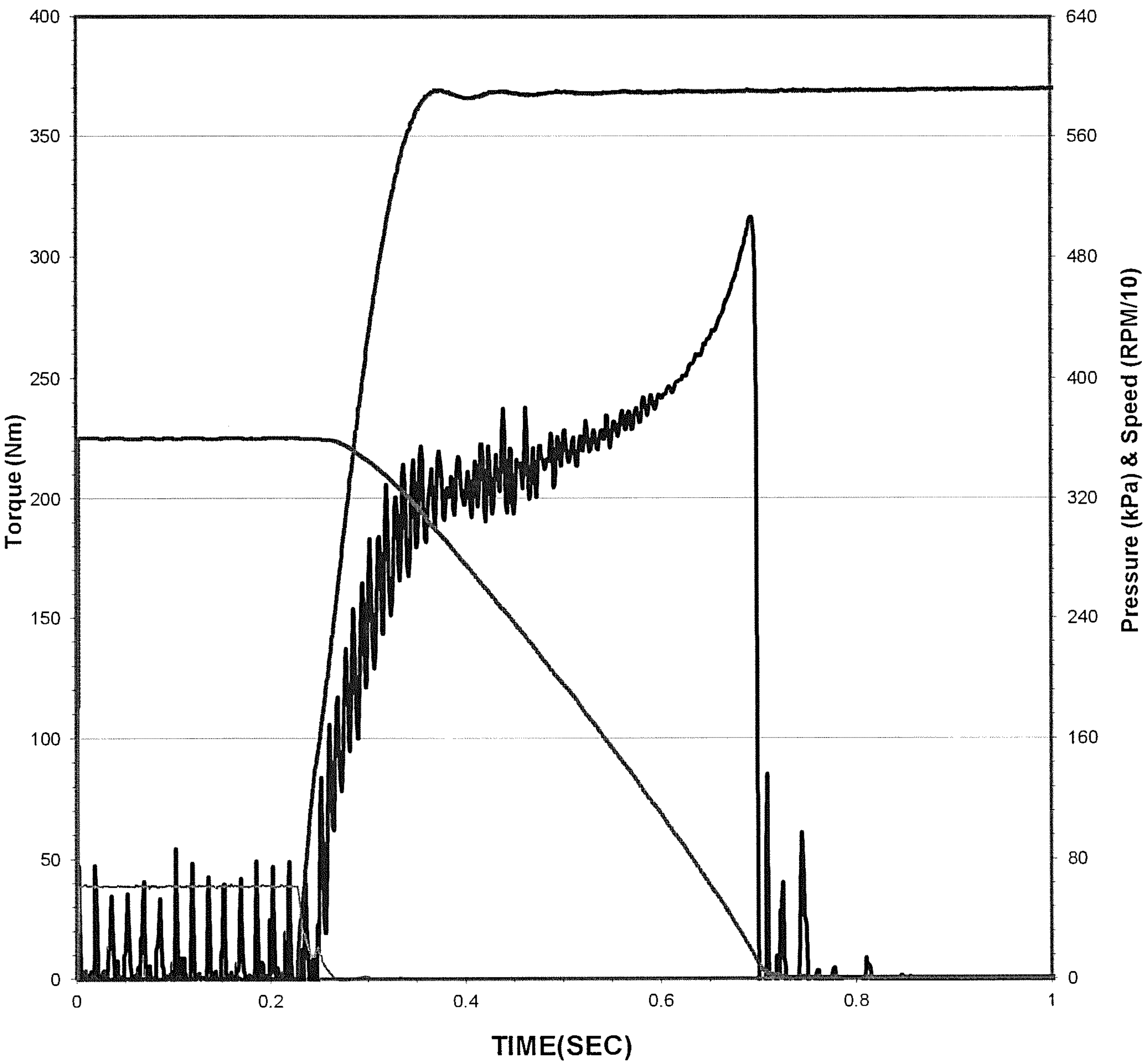
0.2 Sec Dyn:	208 N*m
Midpoint Dyn:	215 N*m
LwSpd Dynamic:	309 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.150

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	19:36:12
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	2500
Temperature:	92.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.472 Sec

Torque

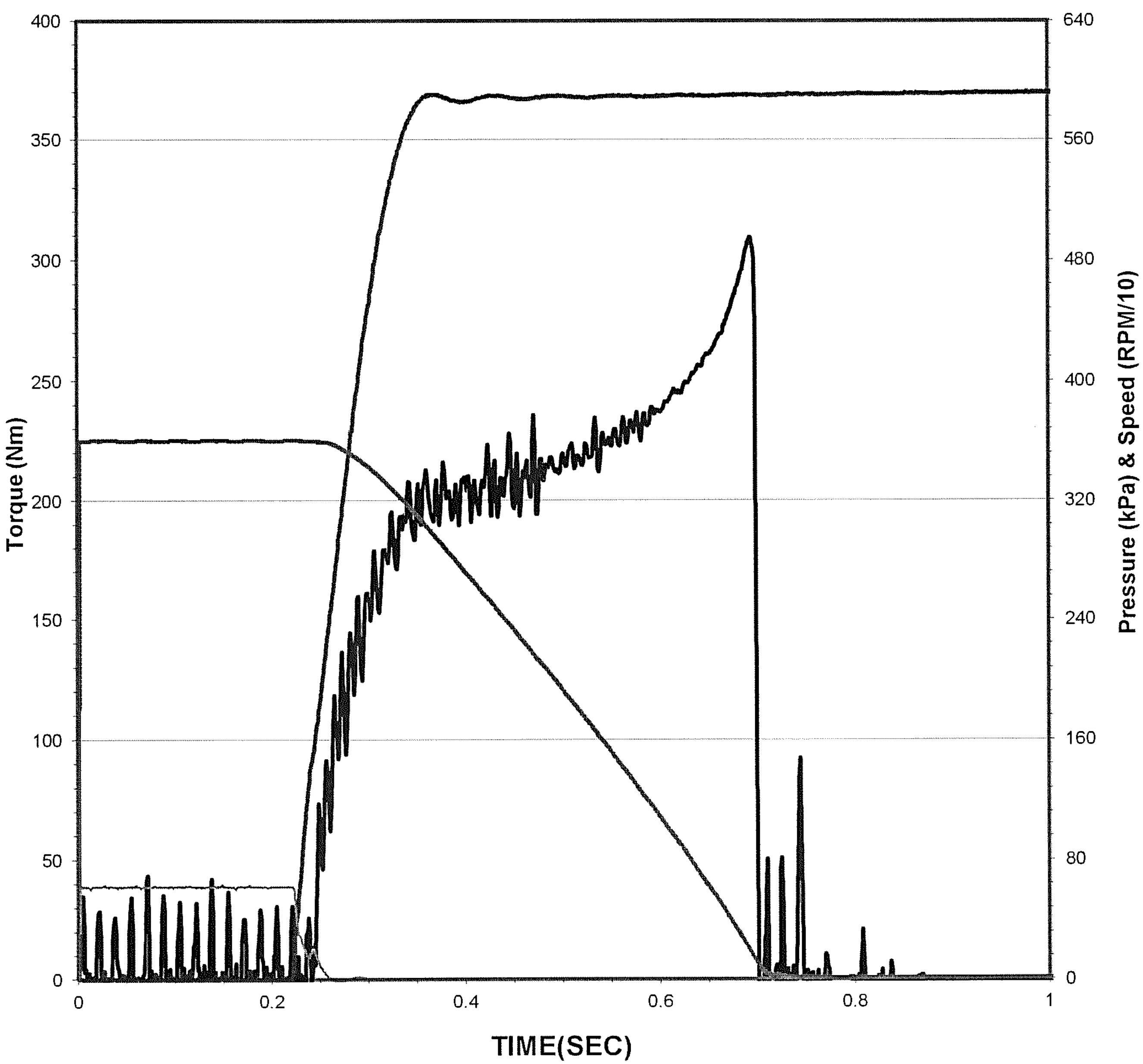
0.2 Sec Dyn:	208 N*m
Midpoint Dyn:	214 N*m
LwSpd Dynamic:	311 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.104
LwSpd Dynamic:	0.151

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/7/2014
Time of Test:	19:36:43
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	2501
Temperature:	86.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.478 Sec

Torque

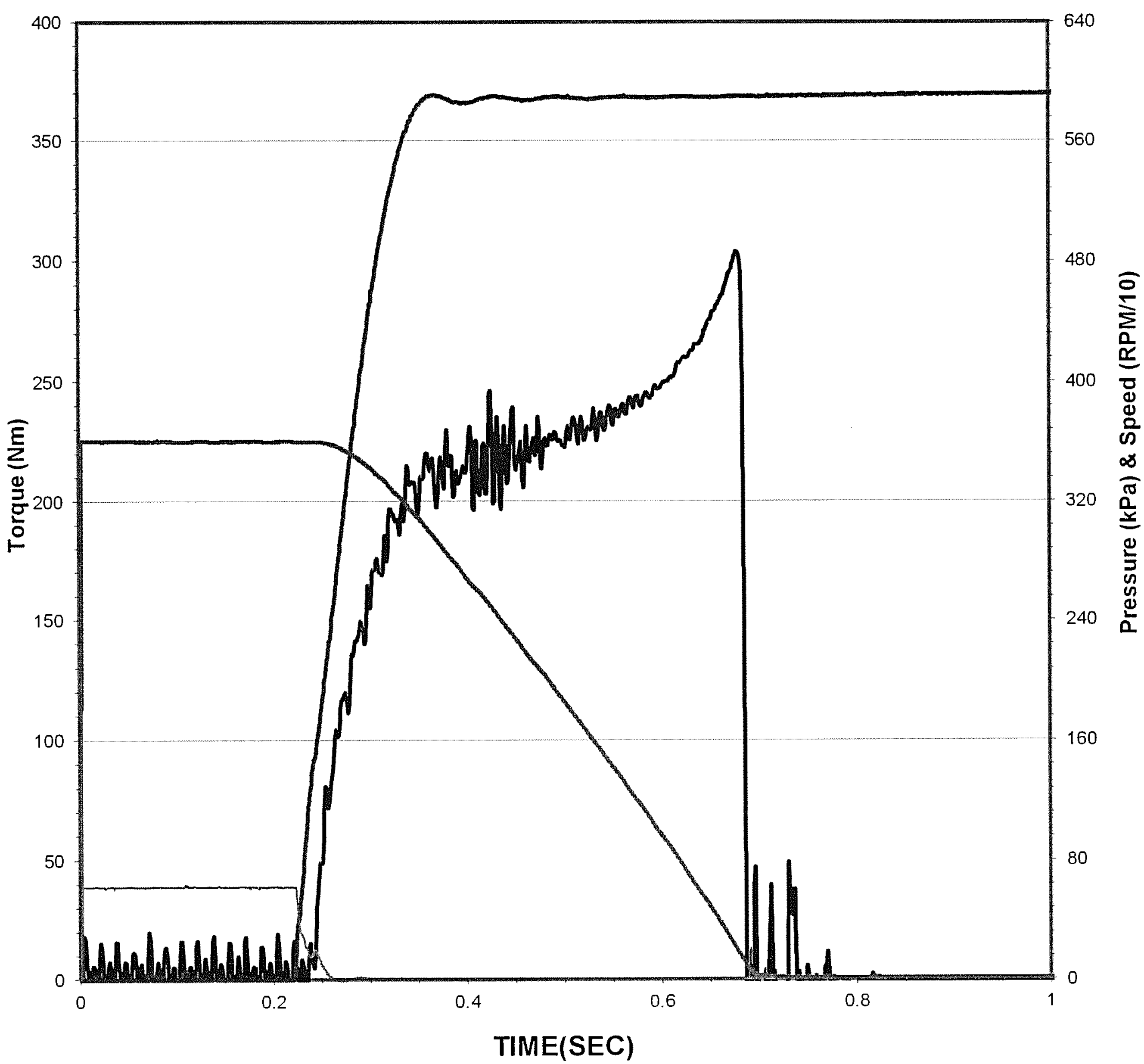
0.2 Sec Dyn:	209 N*m
Midpoint Dyn:	211 N*m
LwSpd Dynamic:	302 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.103
LwSpd Dynamic:	0.147

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/8/2014
Time of Test:	6:01:13
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	4999
Temperature:	91.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.464 Sec

Torque

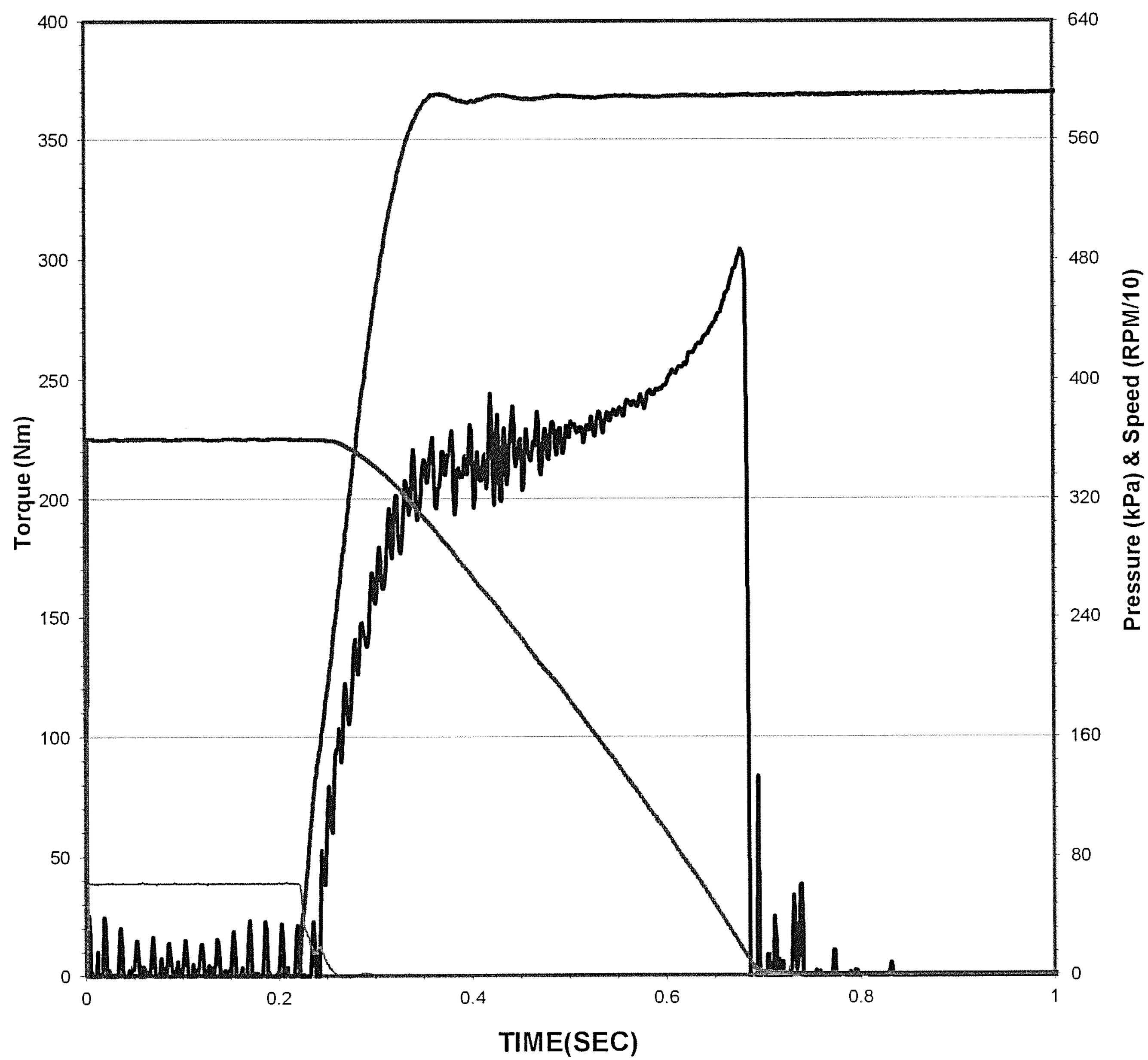
0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	222 N*m
LwSpd Dynamic:	298 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.145

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 3/8/2014

Time of Test: 6:01:28

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 5000

Temperature: 91.5 °C
(93.3 ± 3.0 °C)

Apply Pressure: 588 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.464 Sec

Torque

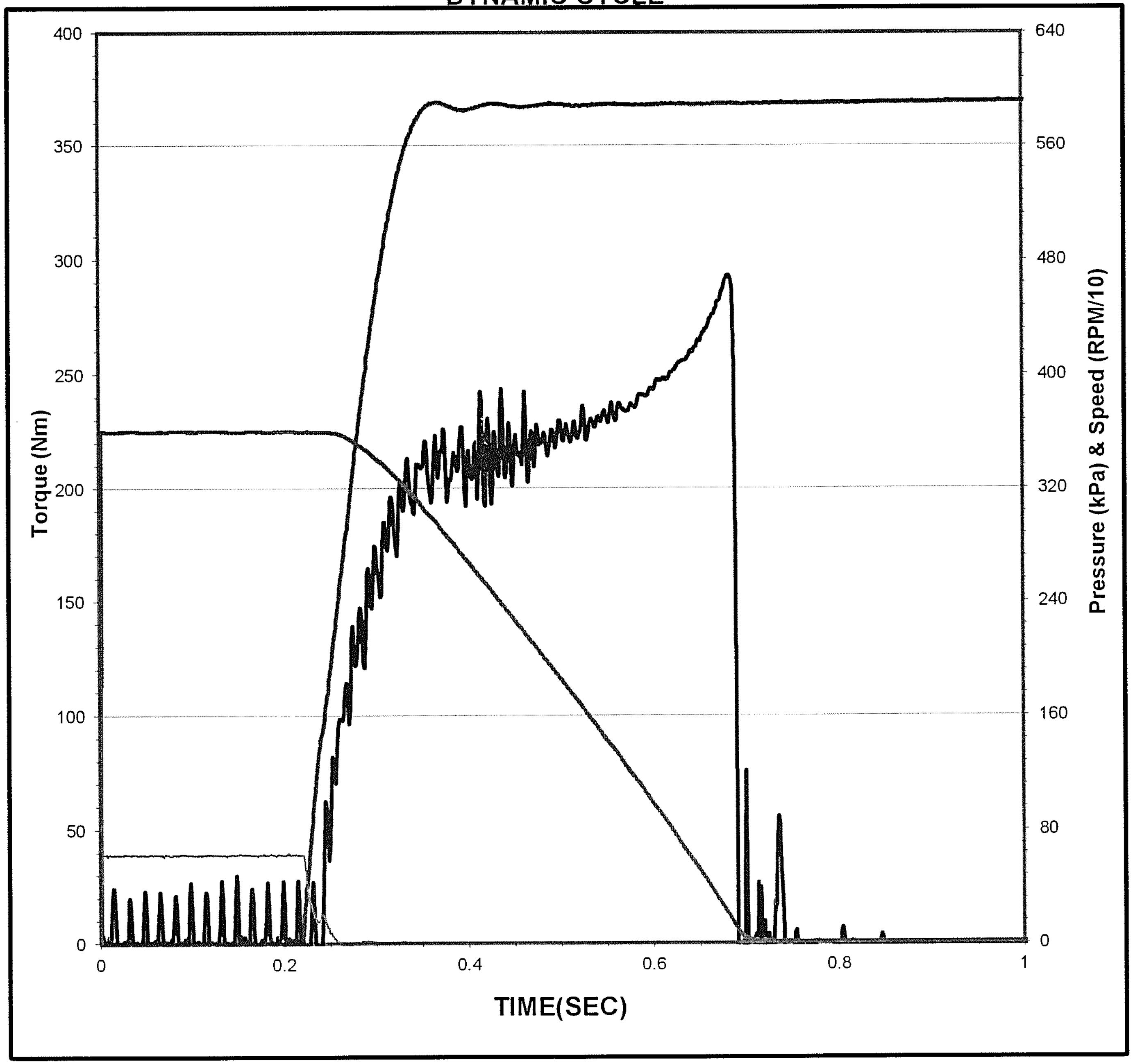
0.2 Sec Dyn: 218 N*m
Midpoint Dyn: 221 N*m
LwSpd Dynamic: 293 N*m

Coefficient of Friction

.2 Sec Dyn: 0.106
Midpoint Dyn: 0.108
LwSpd Dynamic: 0.143

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/8/2014
Time of Test:	6:02:00
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	5001
Temperature:	86.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.469 Sec

Torque

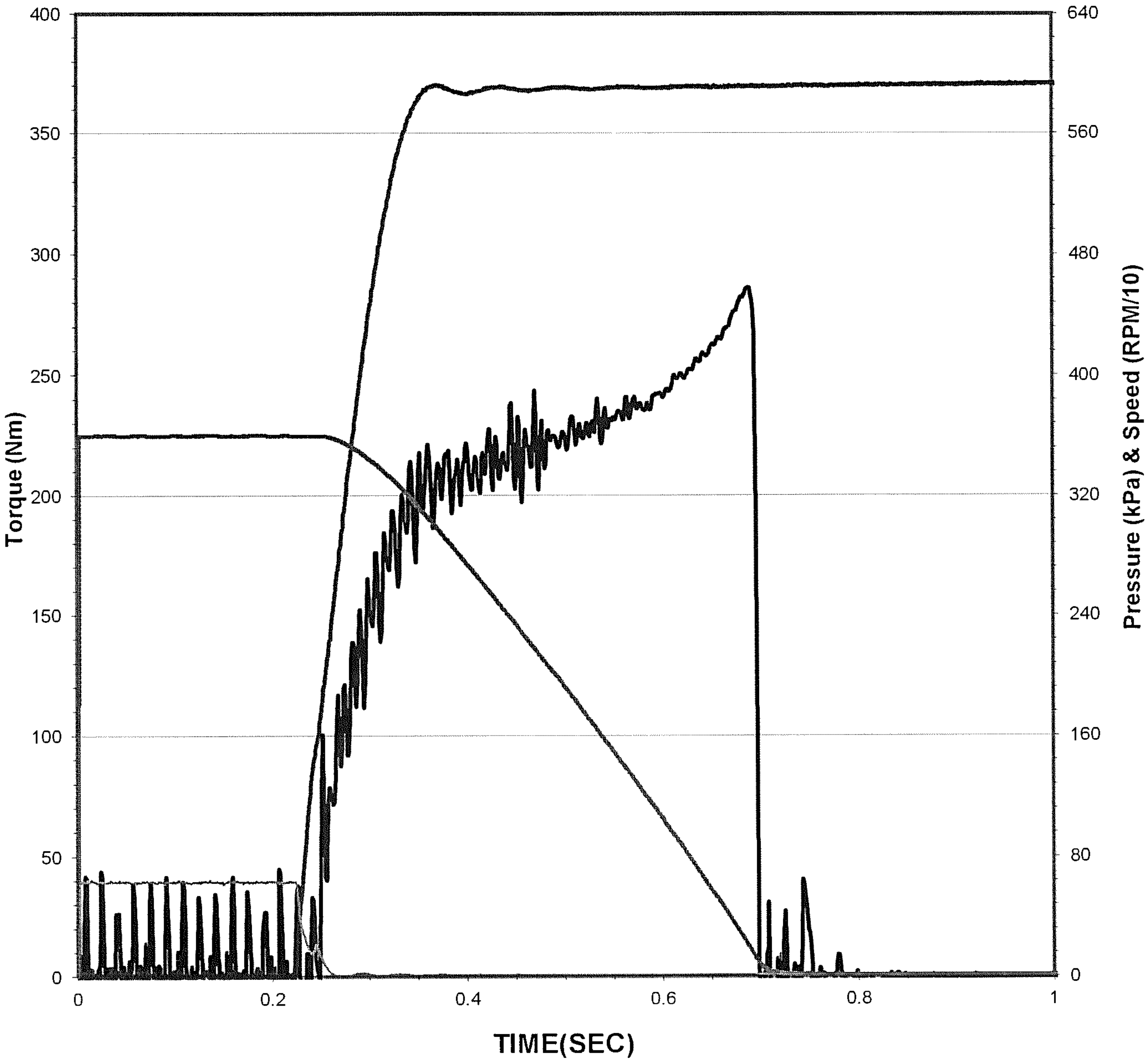
0.2 Sec Dyn:	215 N*m
Midpoint Dyn:	219 N*m
LwSpd Dynamic:	282 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.137

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 3/8/2014

Time of Test: 16:26:30

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 7499

Temperature: 92.3 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.473 Sec

Torque

0.2 Sec Dyn: 216 N*m
Midpoint Dyn: 220 N*m
LwSpd Dynamic: 279 N*m

Coefficient of Friction

.2 Sec Dyn: 0.105
Midpoint Dyn: 0.107
LwSpd Dynamic: 0.136

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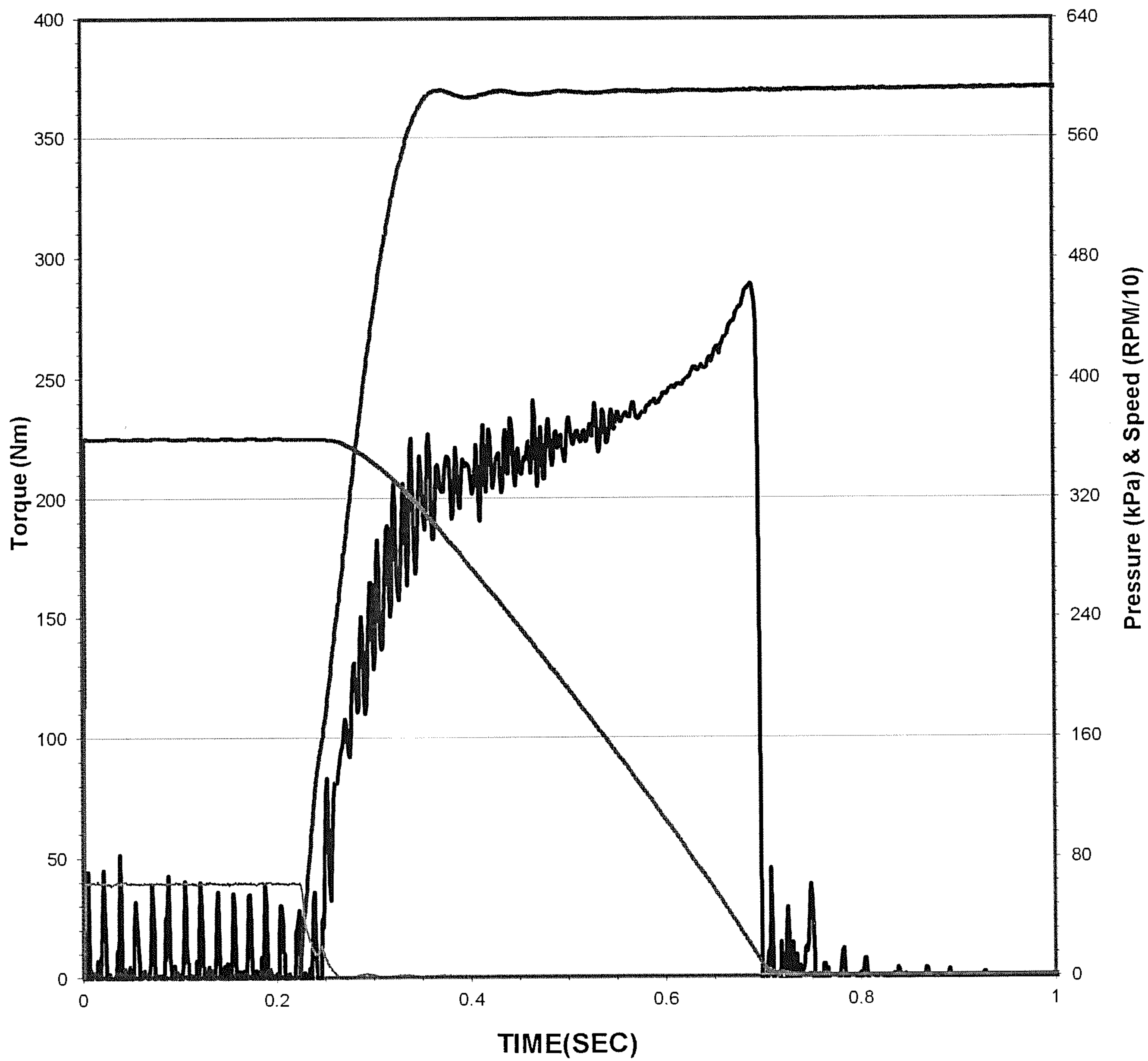
ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/8/2014
Time of Test:	16:26:45
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	7500
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.473 Sec

Torque

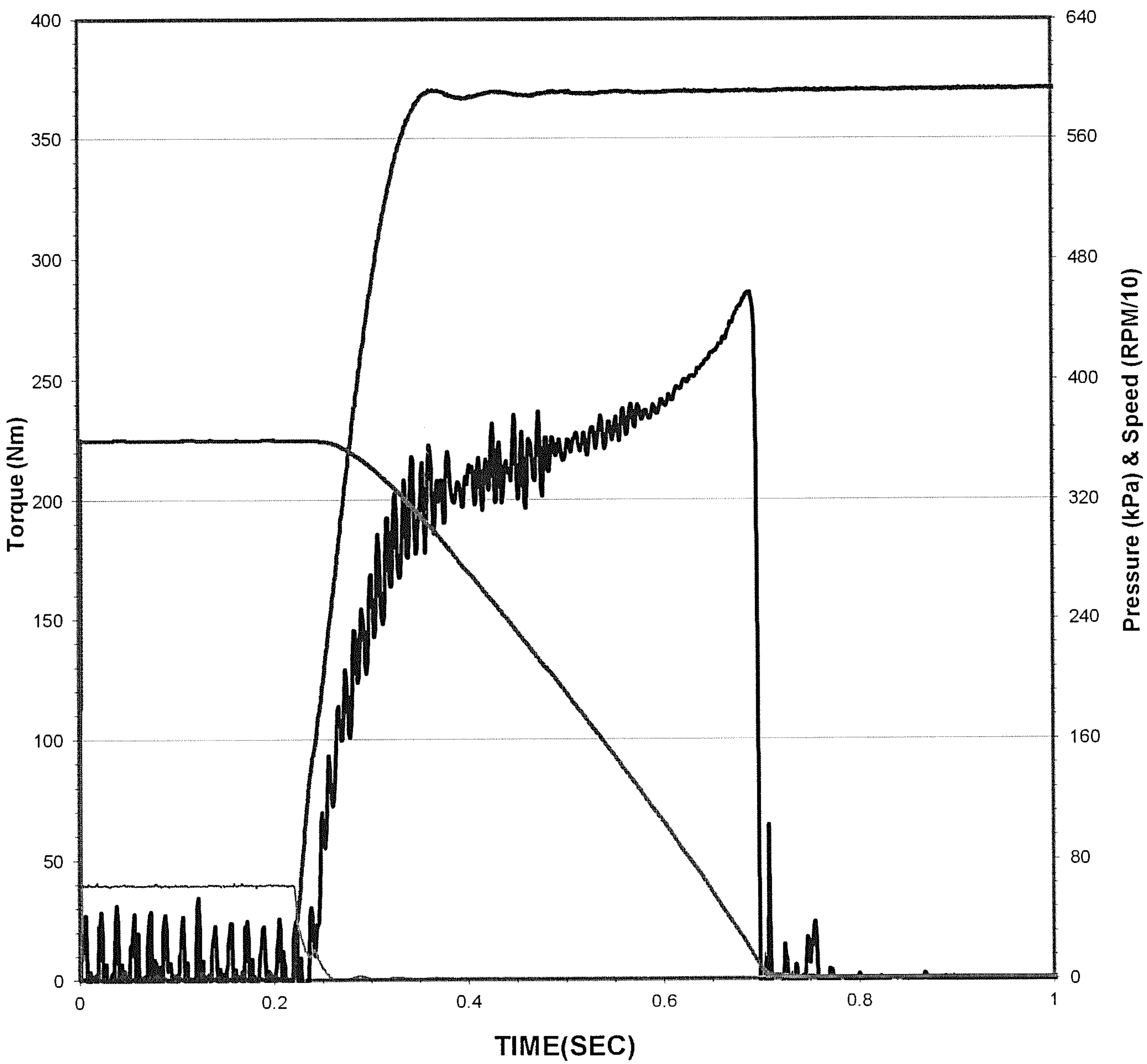
0.2 Sec Dyn:	215 N*m
Midpoint Dyn:	220 N*m
LwSpd Dynamic:	275 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.134

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/8/2014
Time of Test:	16:27:16
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	7501
Temperature:	87.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.478 Sec

Torque

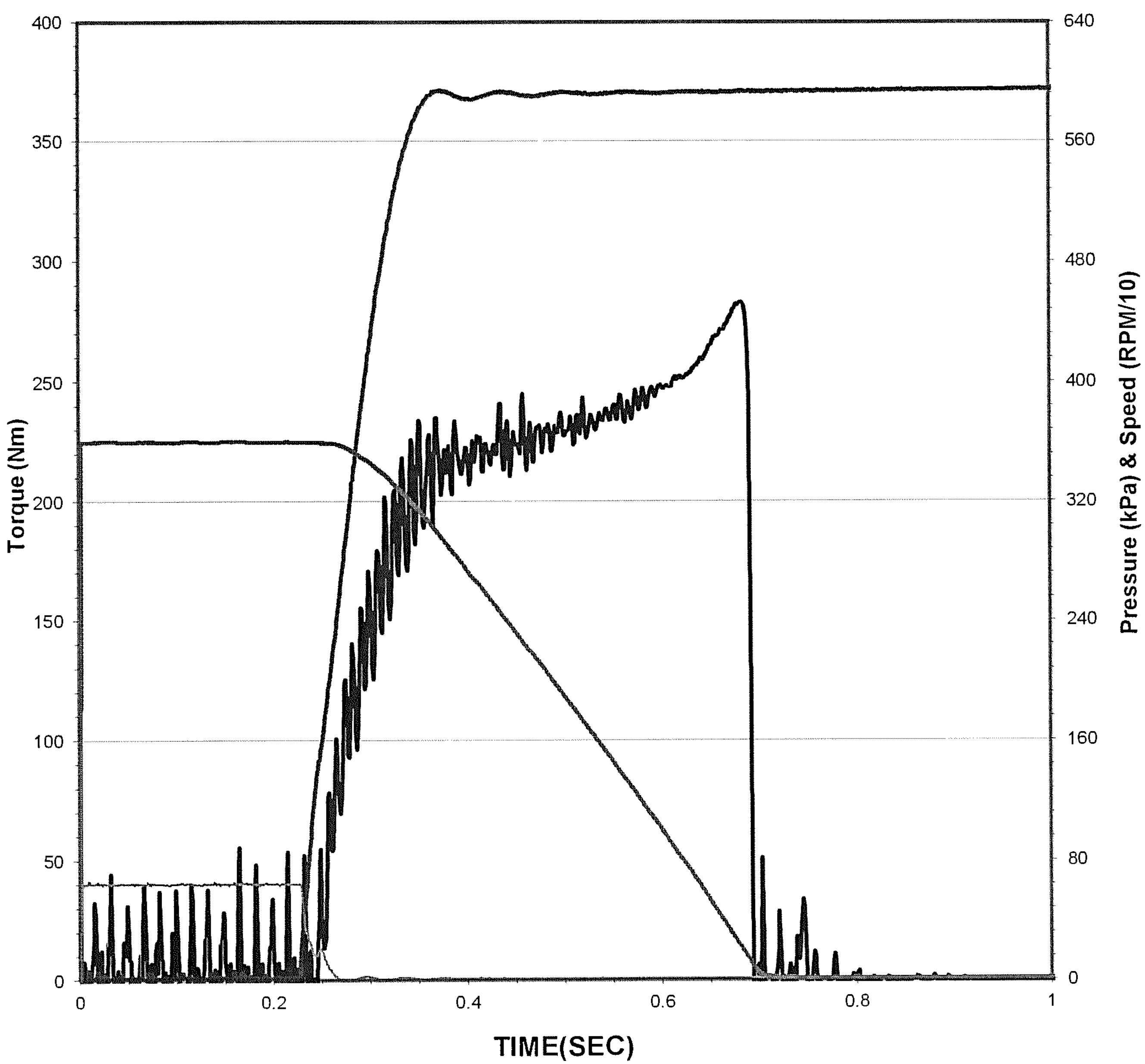
0.2 Sec Dyn:	211 N*m
Midpoint Dyn:	216 N*m
LwSpd Dynamic:	274 N*m

Coefficient of Friction

.2 Sec Dyn:	0.103
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.133

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/9/2014
Time of Test:	3:51:31
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	9998
Temperature:	91.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.464 Sec

Torque

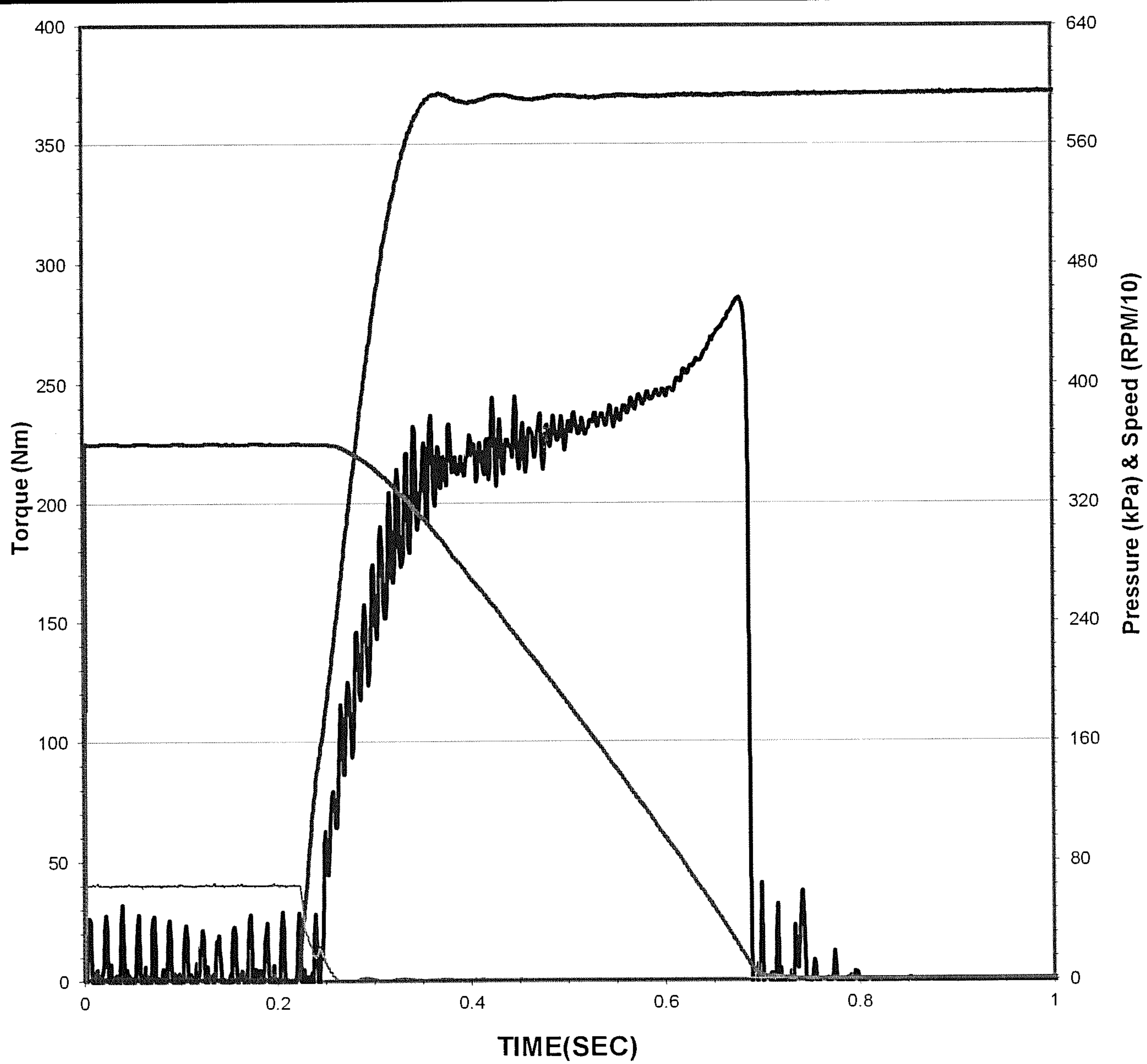
0.2 Sec Dyn:	224 N*m
Midpoint Dyn:	226 N*m
LwSpd Dynamic:	273 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.133

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/9/2014
Time of Test:	3:51:46
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	9999
Temperature:	92.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.465 Sec

Torque

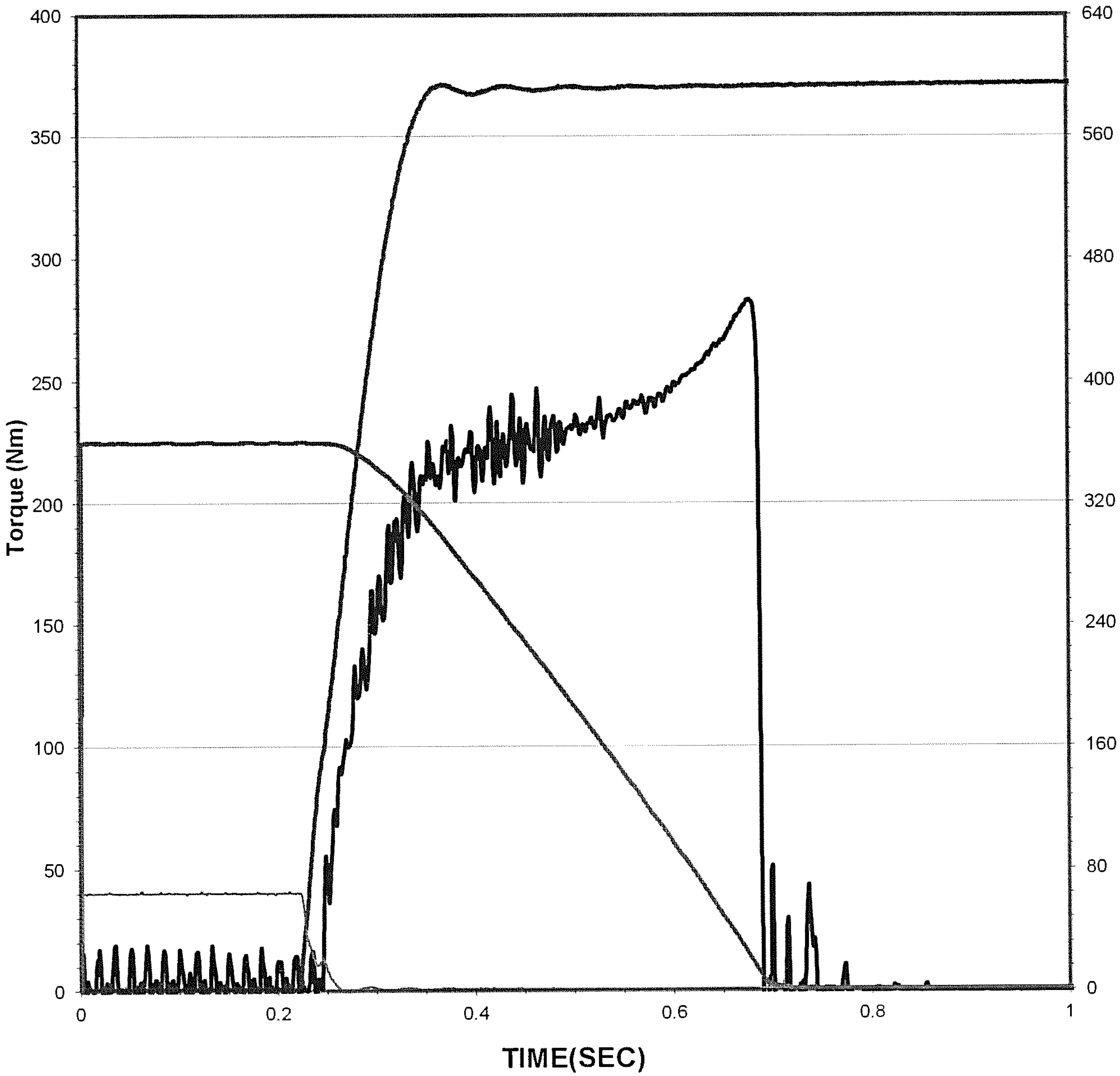
0.2 Sec Dyn:	225 N*m
Midpoint Dyn:	226 N*m
LwSpd Dynamic:	268 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.131

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	3/9/2014
Time of Test:	3:52:01
Test Number:	C2-8-1616
Fluid Code:	LO306520
Cycle Number:	10000
Temperature:	92.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.465 Sec

Torque

0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	226 N*m
LwSpd Dynamic:	275 N*m

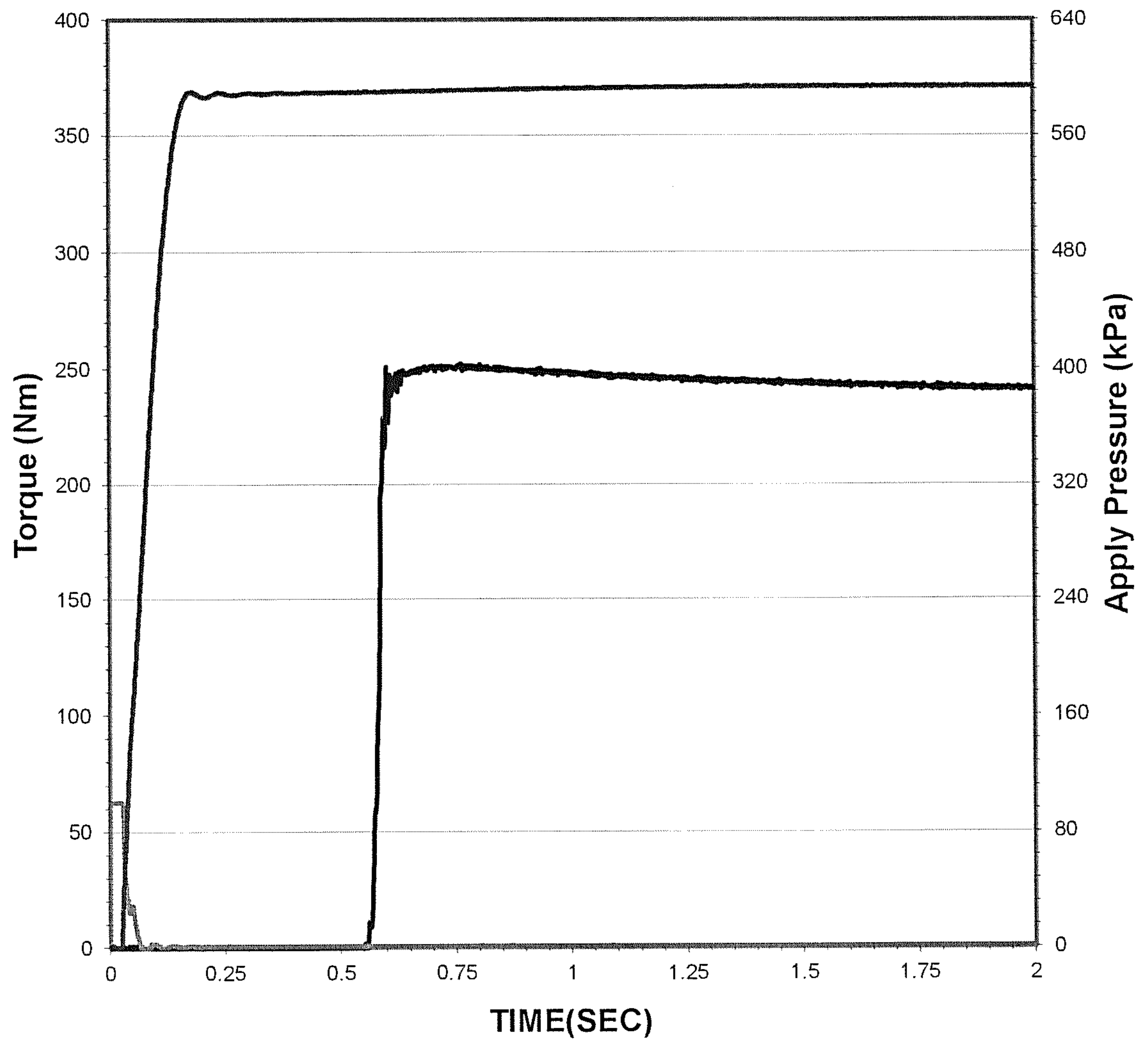
Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.134

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/7/2014

Time of Test: 9:12:53

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 10

STATIC CYCLE

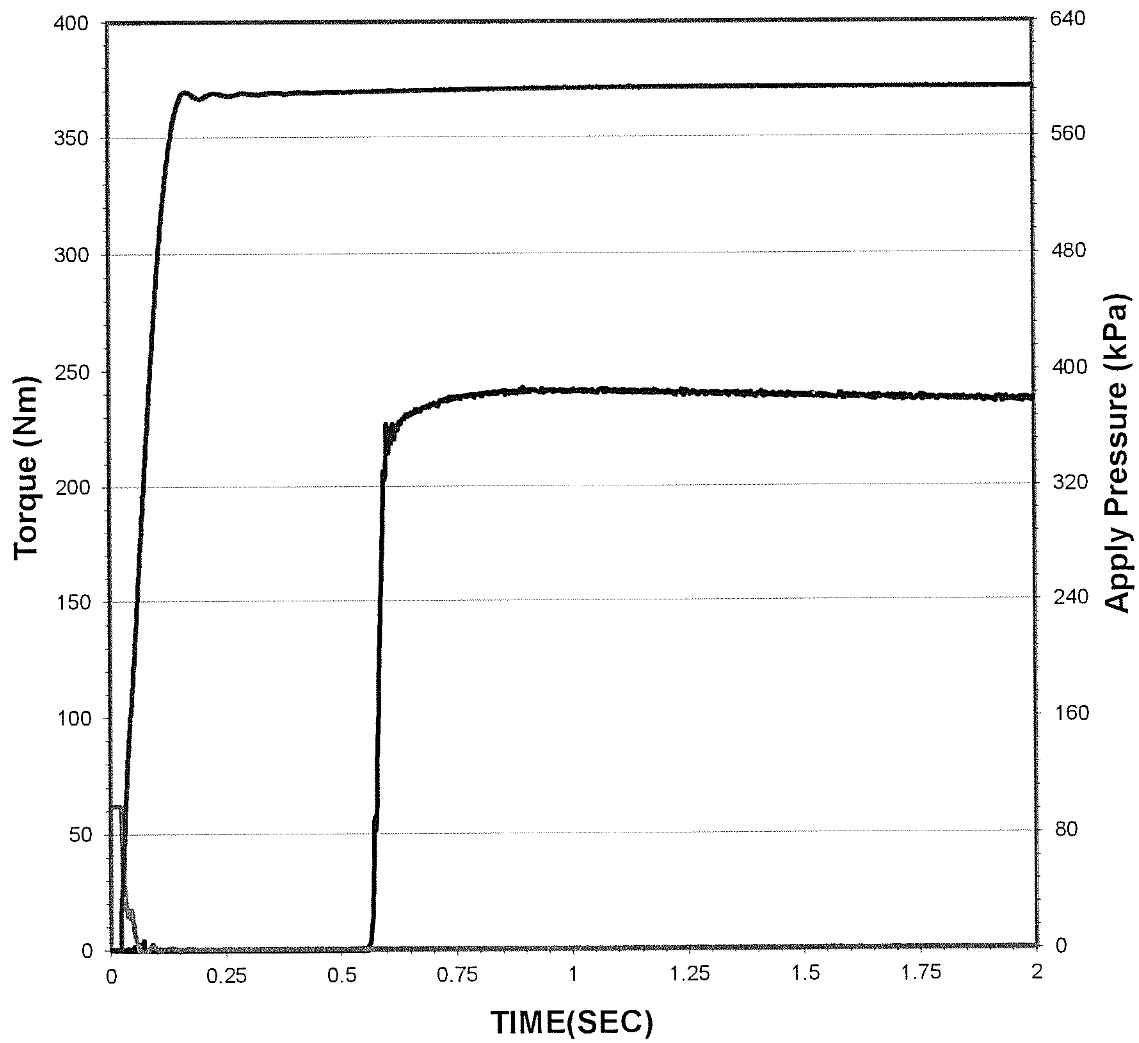
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 252 Nm
.25 Second: 250 Nm

Coefficient of Friction
Static Peak: 0.123
.25 Second: 0.122

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/7/2014

Time of Test: 9:35:39

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 100

STATIC CYCLE

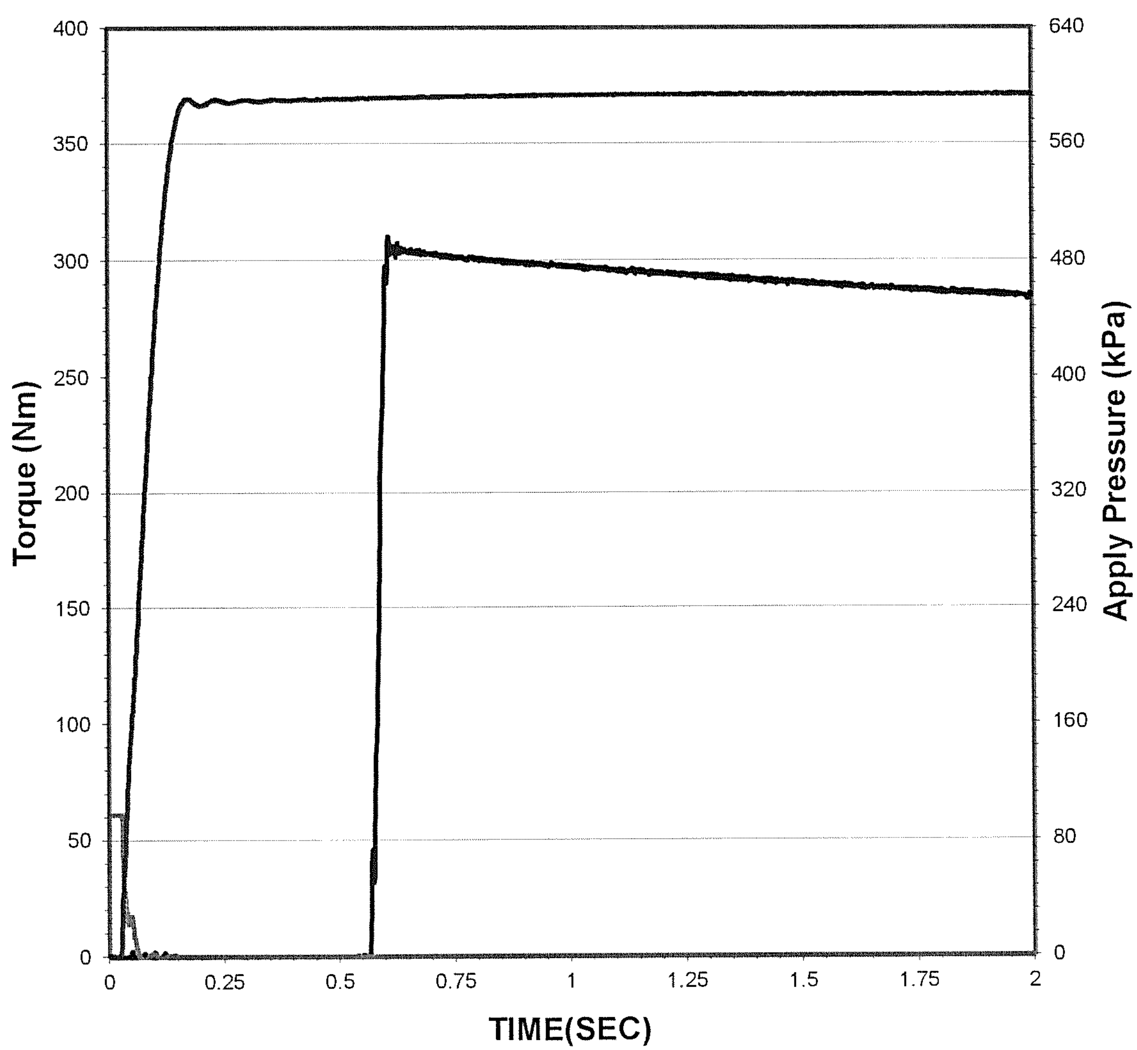
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 243 Nm
.25 Second: 240 Nm

Coefficient of Friction
Static Peak: 0.118
.25 Second: 0.117

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/7/2014

Time of Test: 11:15:56

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 500

STATIC CYCLE

Apply Pressure:
At .25 Second: 589 kPa

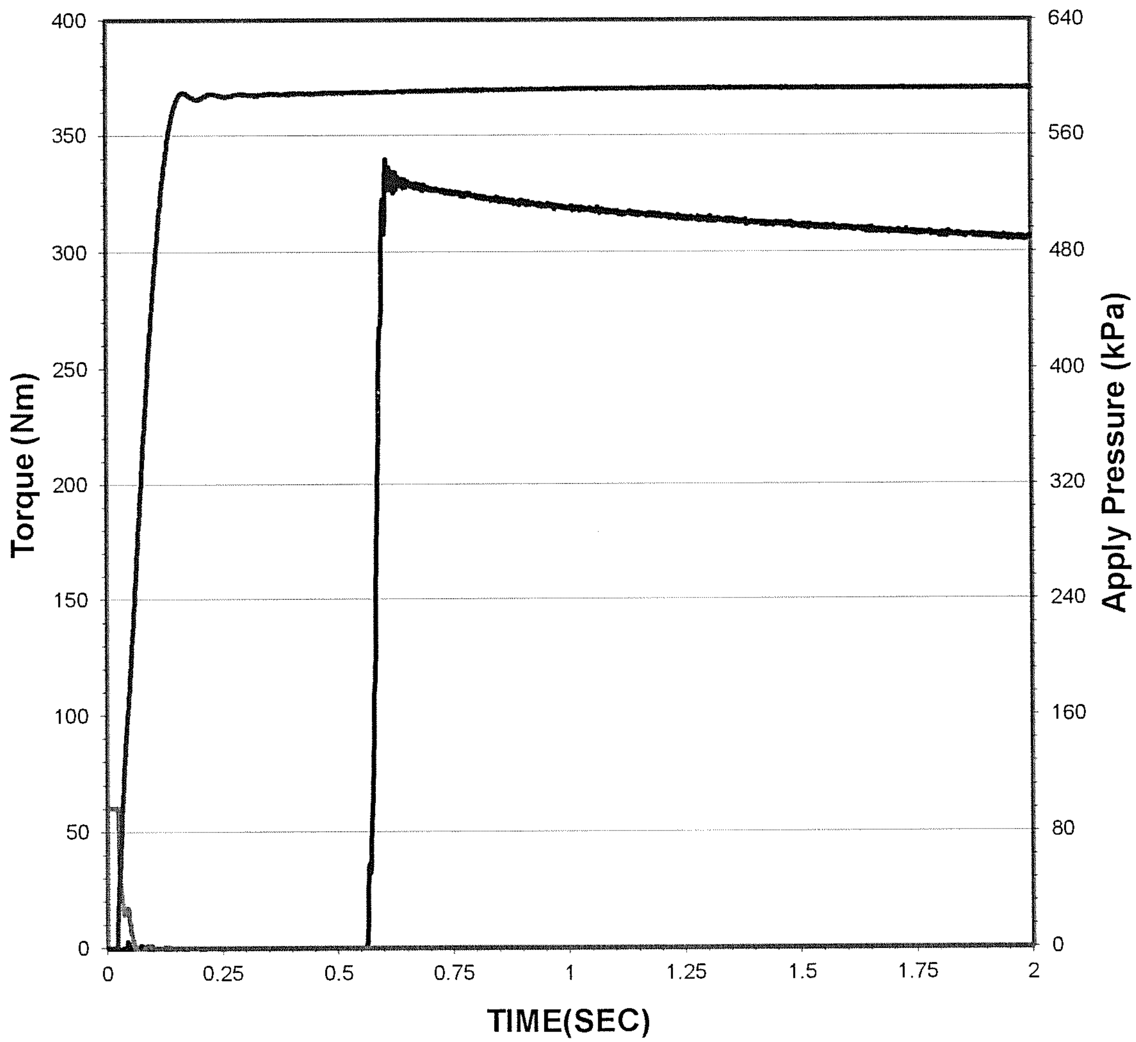
Torque
Static Peak: 310 Nm
.25 Second: 300 Nm

Coefficient of Friction
Static Peak: 0.151
.25 Second: 0.146

A-202

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/7/2014

Time of Test: 13:21:12

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 1000

STATIC CYCLE

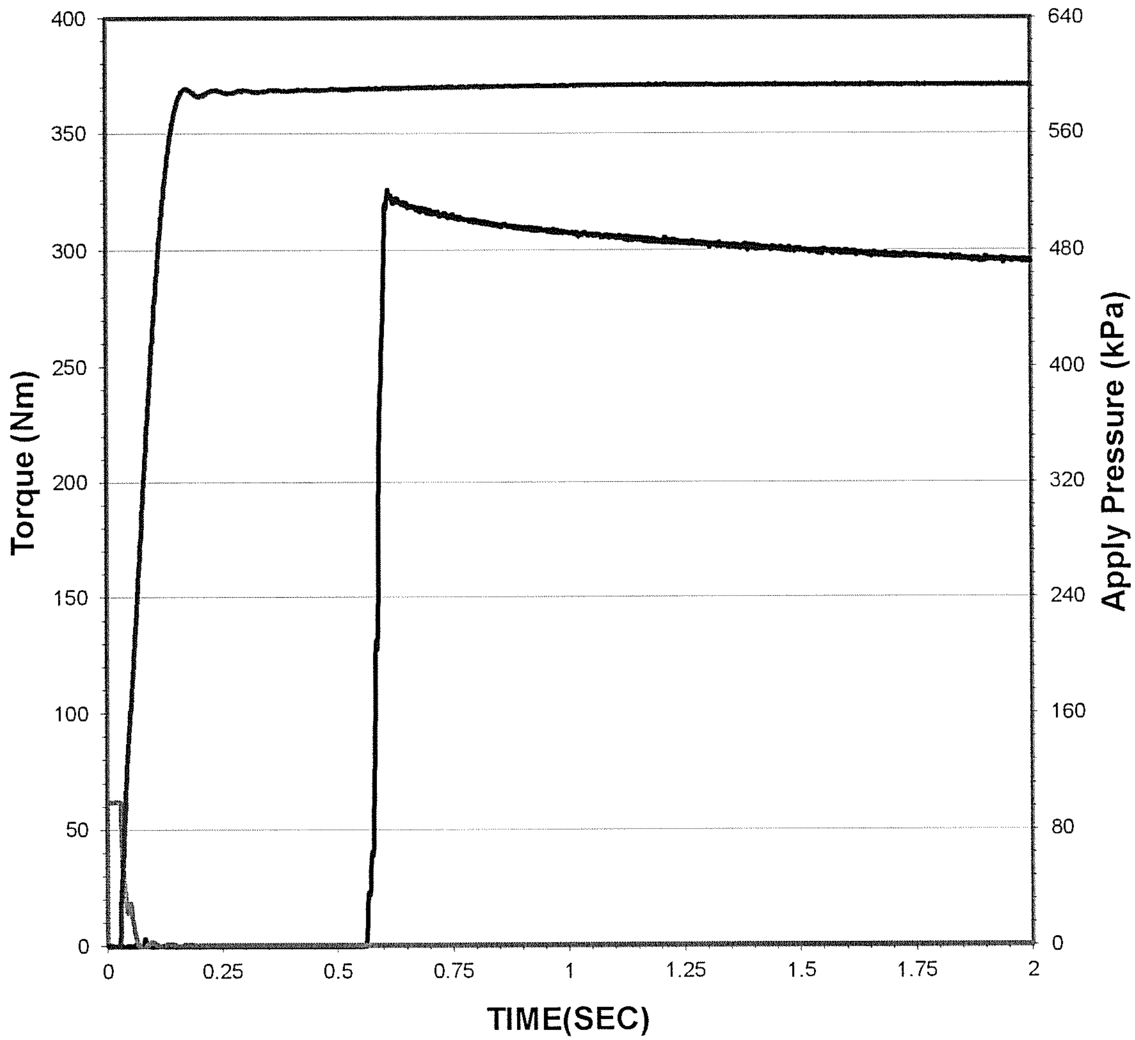
Apply Pressure:
At .25 Second: 587 kPa

Torque
Static Peak: 340 Nm
.25 Second: 324 Nm

Coefficient of Friction
Static Peak: 0.166
.25 Second: 0.158

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/7/2014

Time of Test: 19:36:28

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 2500

STATIC CYCLE

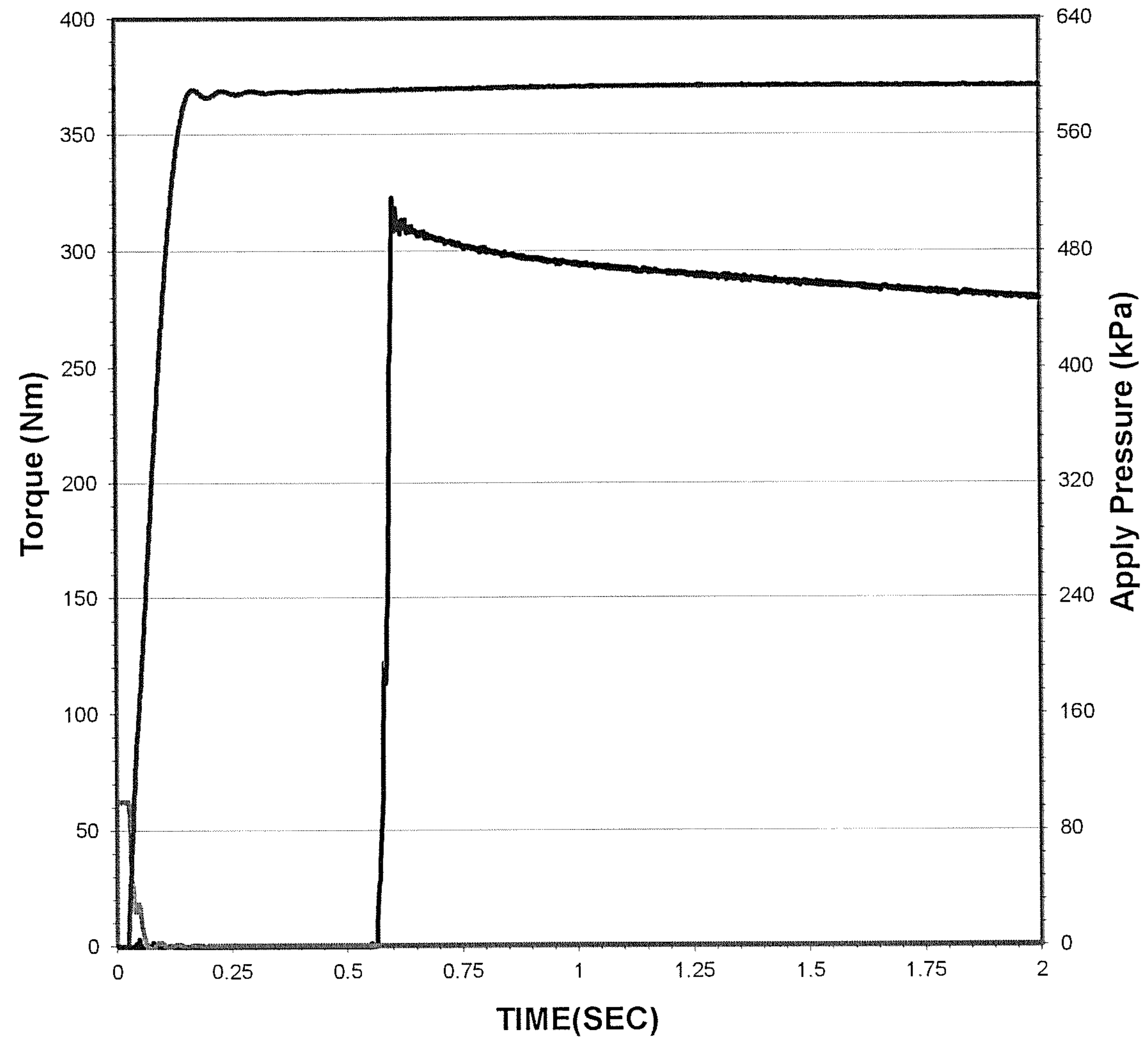
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 326 Nm
.25 Second: 313 Nm

Coefficient of Friction
Static Peak: 0.159
.25 Second: 0.152

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/8/2014

Time of Test: 6:01:44

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 5000

STATIC CYCLE

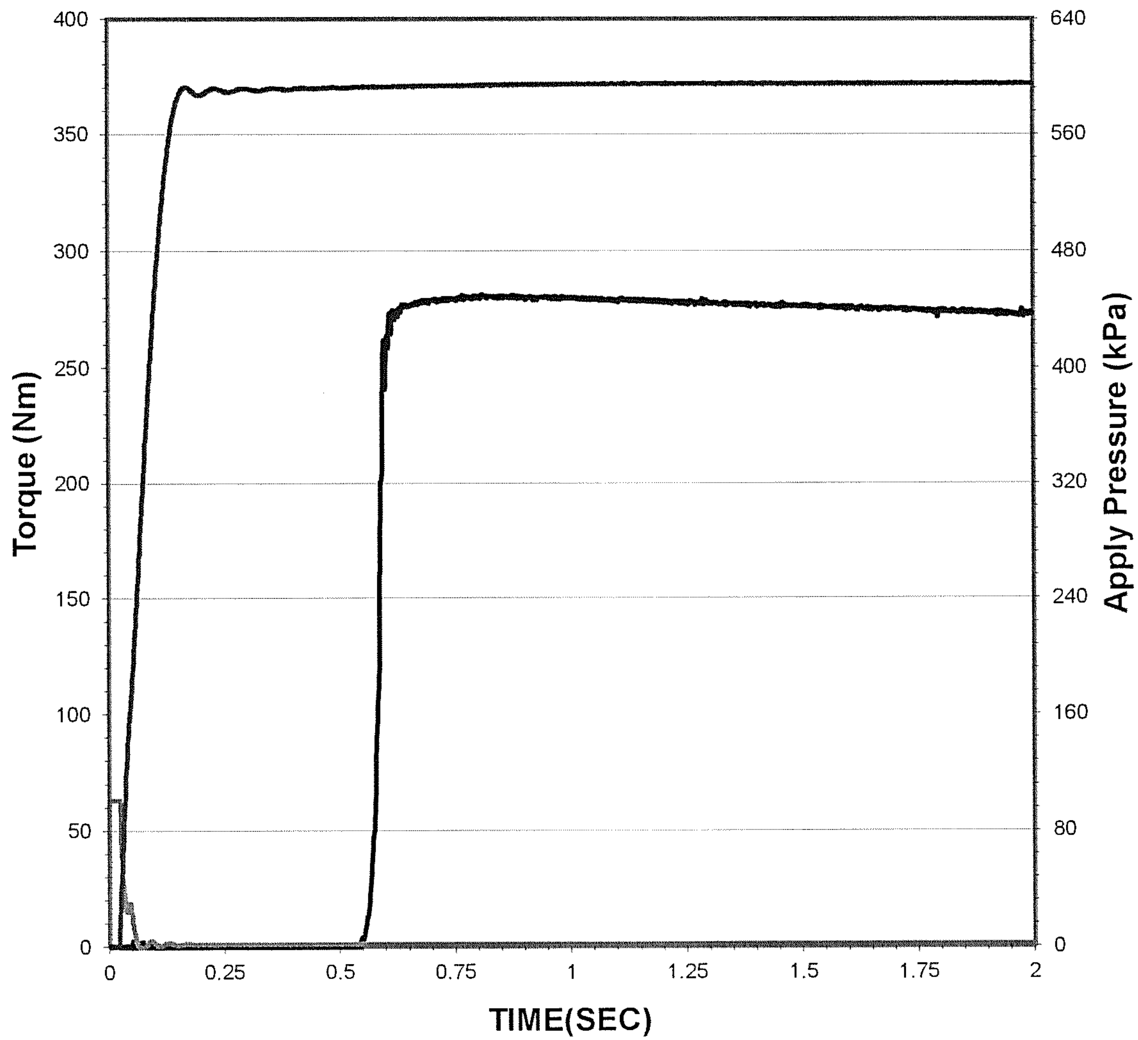
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 323 Nm
.25 Second: 301 Nm

Coefficient of Friction
Static Peak: 0.157
.25 Second: 0.146

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/8/2014

Time of Test: 16:27:01

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 7500

STATIC CYCLE

Apply Pressure:
At .25 Second: 589 kPa

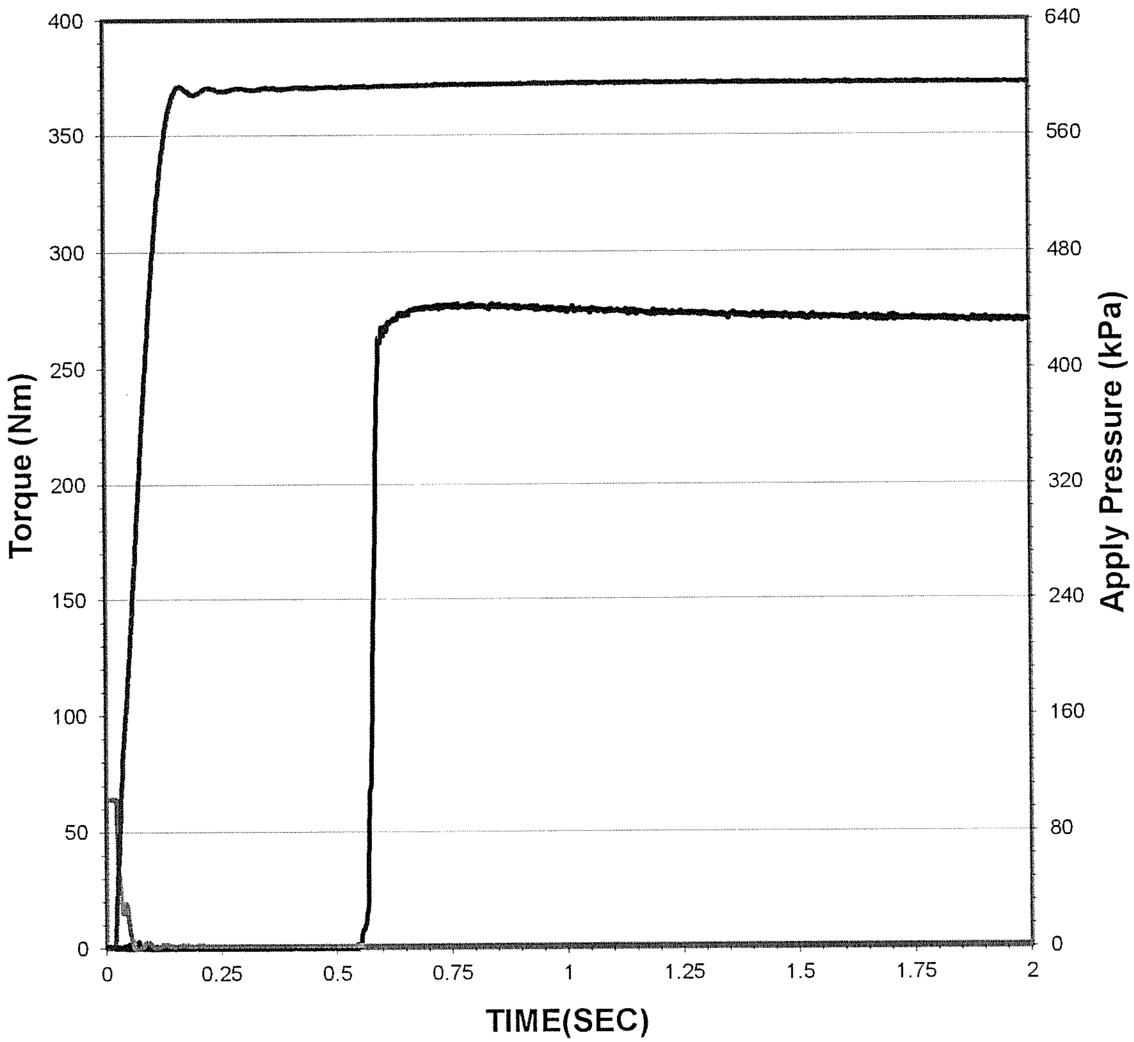
Torque
Static Peak: 282 Nm
.25 Second: 280 Nm

Coefficient of Friction
Static Peak: 0.137
.25 Second: 0.137

A-206

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 3/9/2014

Time of Test: 3:52:17

Test Number: C2-8-1616

Fluid Code: LO306520

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 277 Nm
.25 Second: 276 Nm

Coefficient of Friction
Static Peak: 0.135
.25 Second: 0.134

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
SEQUENCE 1220 ONLY

Conducted for

ARMY LAB

Oil Code:
LO306520

Test Number:
A-133-I

April 9, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
Summary Sheet

Company: ARMY LAB

Test start date: 4/9/2014
End of test date: 4/9/2014
Oil Code: LO306520

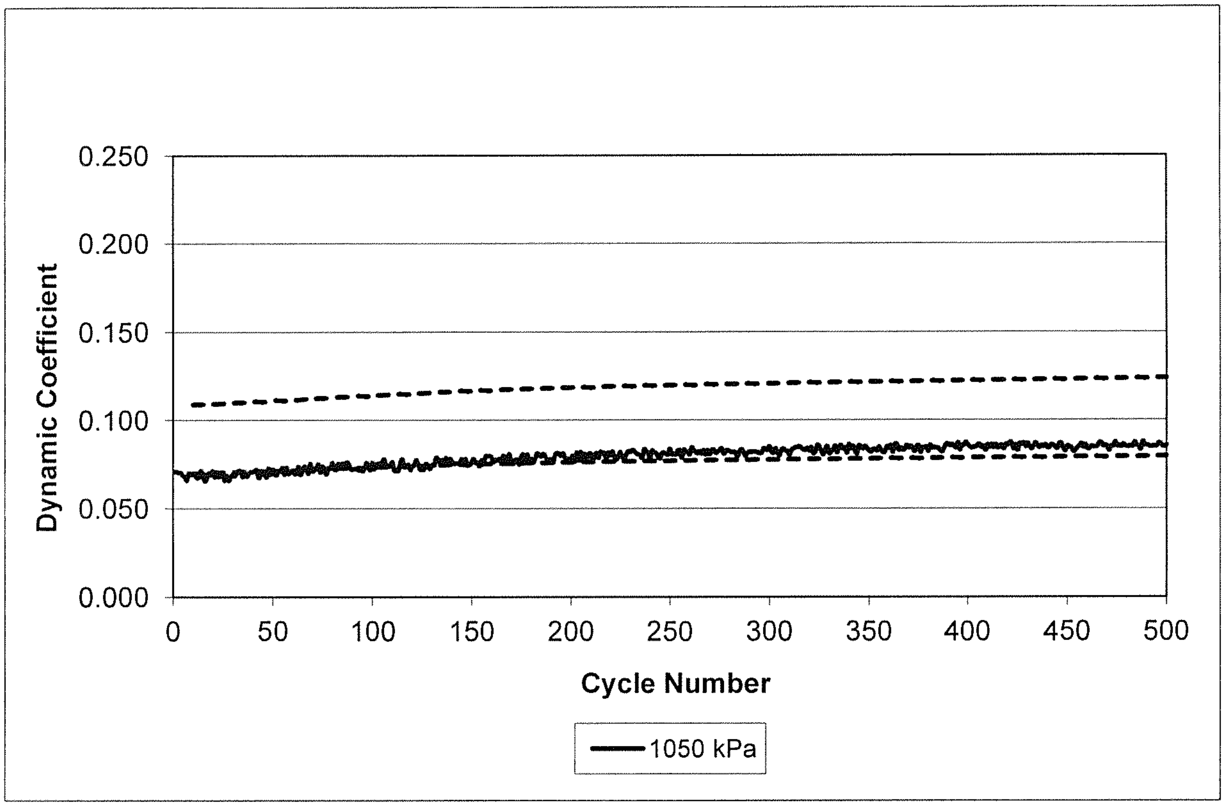
Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		F					
Dynamic Coefficient Vs. Load:		F					
Dynamic Coefficient Vs. Speed:		P					
Energy Limit:		P					
Static Coefficient Vs. Load:		P					
Static Coefficient Vs. Speed:		P					
Energy Limit:		P					
Total Wear:		0.012					
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand using 2009 batch parts.
The results are compared to TO-4 testing limits.

P = Pass
N/A = Not Applicable

Test name:	A-133-I
Test date:	4/9/2014
Test description:	LO306520
Oil type:	
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12
Run name & desc:	A-133-I
Run date:	4/9/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	1220
Remarks:	
Number of cylces run:	1195
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	
Disc name & desc:	1Y0709
Material:	SINTERED BRONZE
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	007130C800012
Remarks:	
Plate Name & desc:	8E4095
Surface:	0.95
Miscellaneous:	
Batch Number:	007130C800012
Remarks:	
Report limit name:	R-004-I
Limit file generated:	8/22/2012
Report format name:	REP1220 - SINTERED BRONZE

Test: A-133-I
Run: A-133-I
Started on: 4/9/2014 at 07:31:28

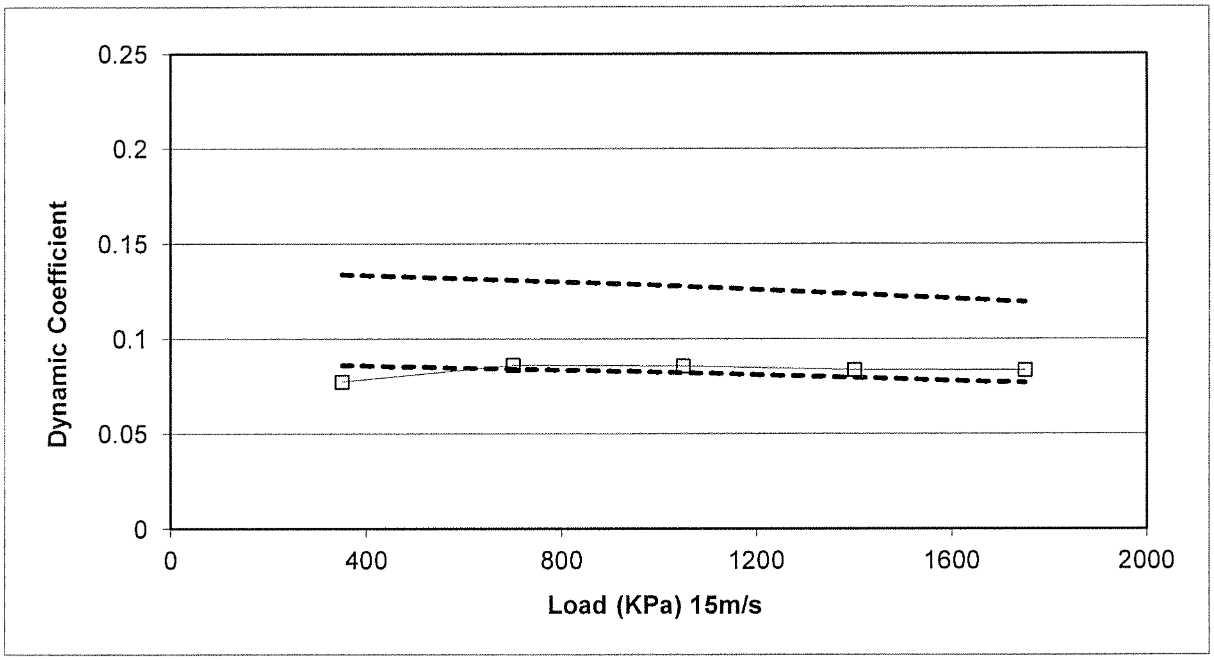


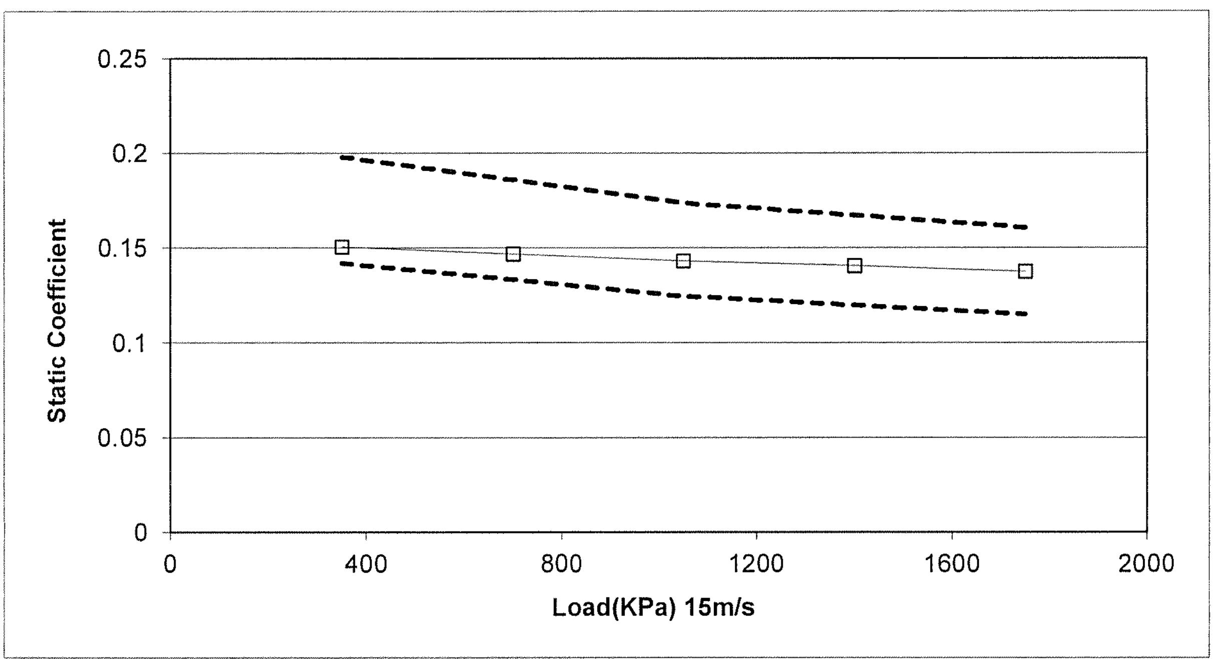
Wear Measurements
Thickness

Location	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
II	4.94	4.93	4.93	4.94	4.94	4.94
T	4.97	4.96	4.96	4.96	4.95	4.95
+	4.97	4.95	4.95	4.97	4.96	4.95
X	4.96	4.95	4.95	4.95	4.94	4.94
Y	4.96	4.95	4.95	4.96	4.95	4.95
Z	4.95	4.94	4.94	4.95	4.94	4.94
Average	4.96	4.95	4.95	4.95	4.95	4.94

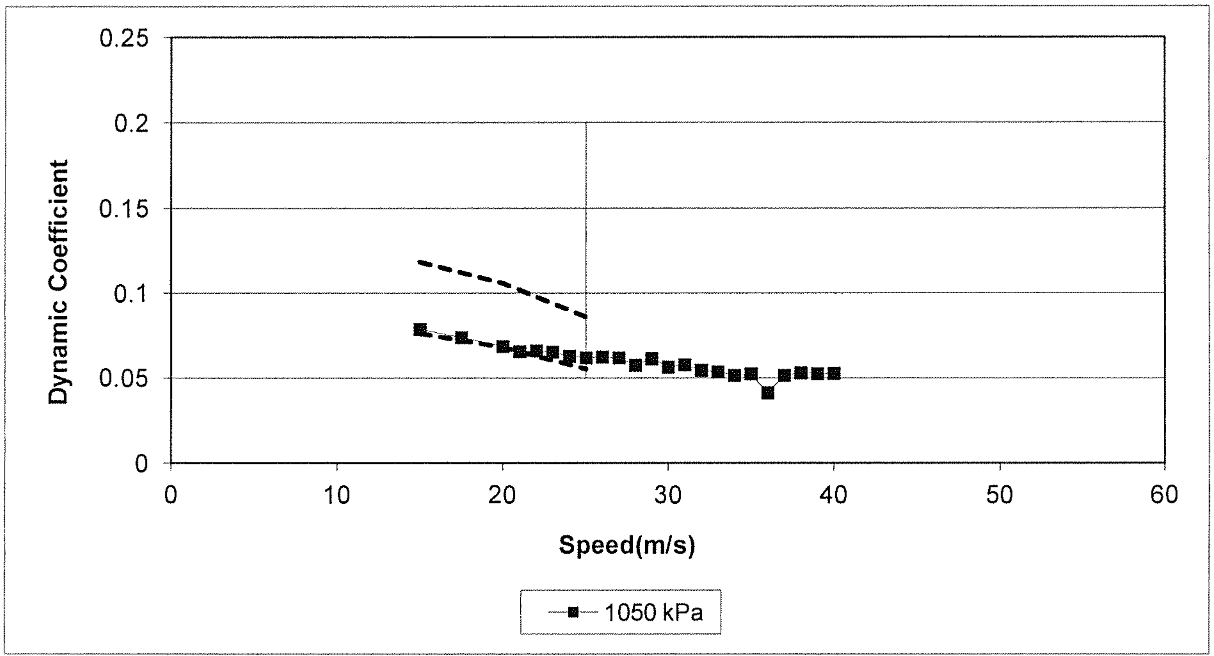
M1-M2 Compression set average wear: 0.012
M2-M3 average Wear: 0.000
Total Wear(all measurements in mm): 0.012

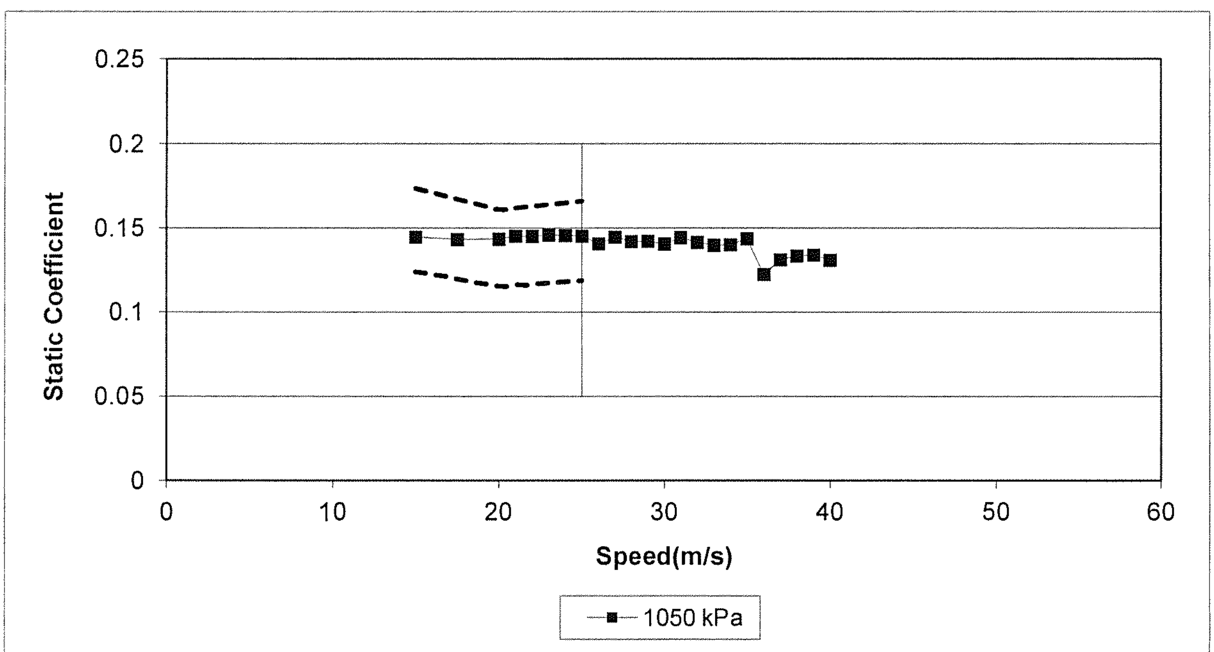
Test: A-133-I
Run: A-133-I
Started on: 4/9/2014 at 07:31:28



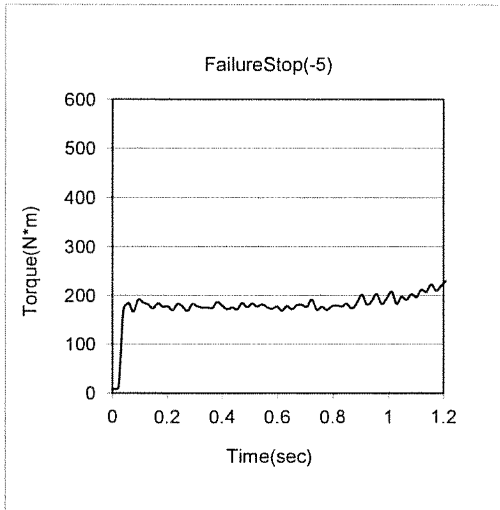


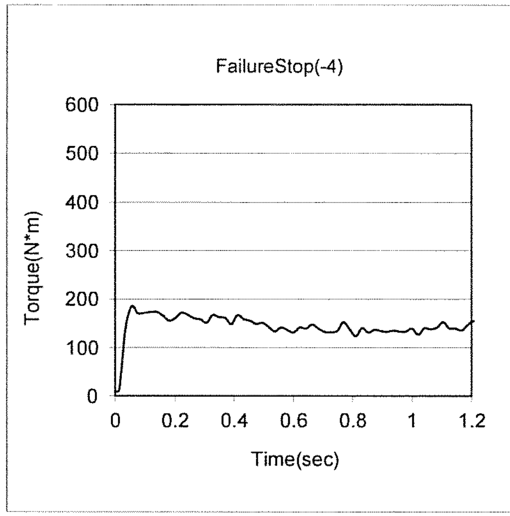
Test: A-133-I
Run: A-133-I
Started on: 4/9/2014 at 07:31:28

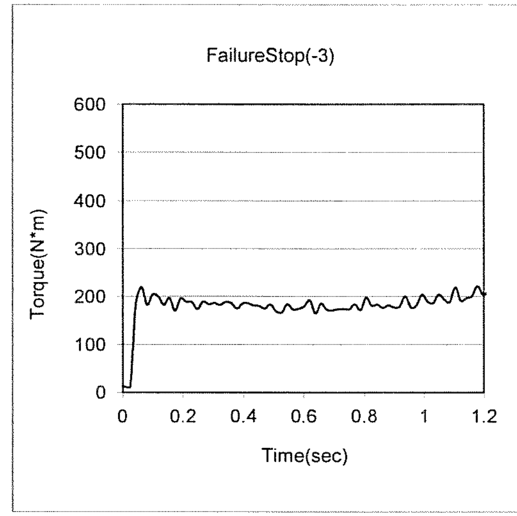


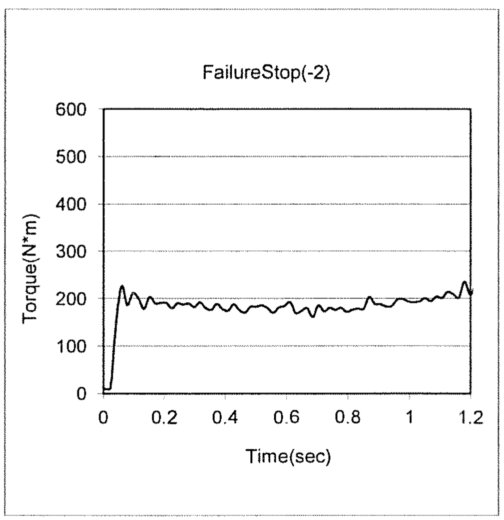


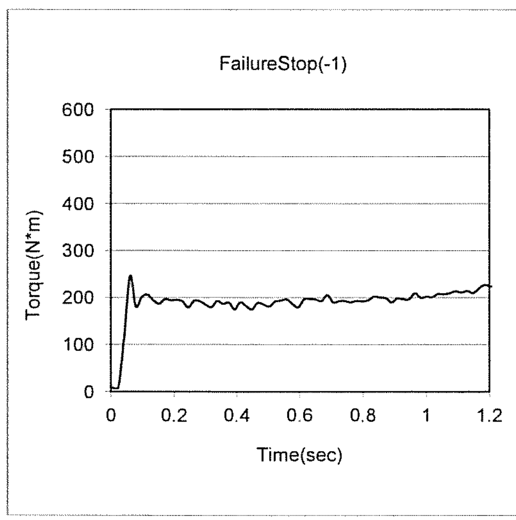
Test: A-133-I
Run: A-133-I
Started on: 4/9/2014 at 07:31:28

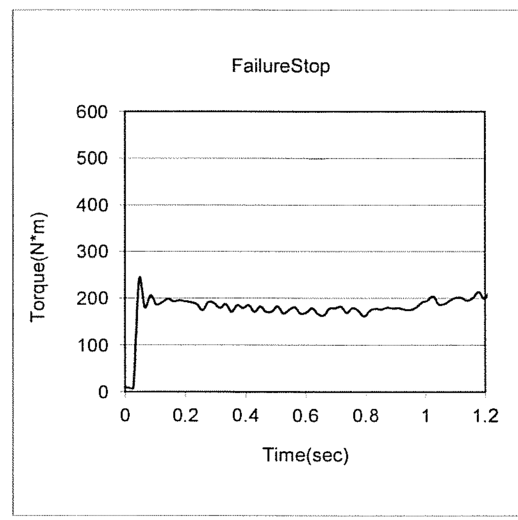












SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
SEQUENCE 1222 ONLY

Conducted for

ARMY LAB

Oil Code:
LO306520

Test Number:
A-134-I

April 10, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
Summary Sheet

Company: ARMY LAB

Test start date: 4/10/2014
End of test date: 4/10/2014
Oil Code: LO306520

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:				F			
Dynamic Coefficient Vs. Load:				F			
Dynamic Coefficient Vs. Speed:				P			
Energy Limit:				F			
Static Coefficient Vs. Load:				F			
Static Coefficient Vs. Speed:				P			
Energy Limit:				F			
Total Wear:				0.020			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand using 2009 batch parts. The results are compared to TO-4 testing limits.

P = Pass
N/A = Not Applicable

Test name:	A-134-I
Test date:	4/10/2014
Test description:	
Oil type:	LO306520
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12

Run name & desc:	A-134-I
Run date:	4/10/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	1222
Remarks:	
Number of cylces run:	1006

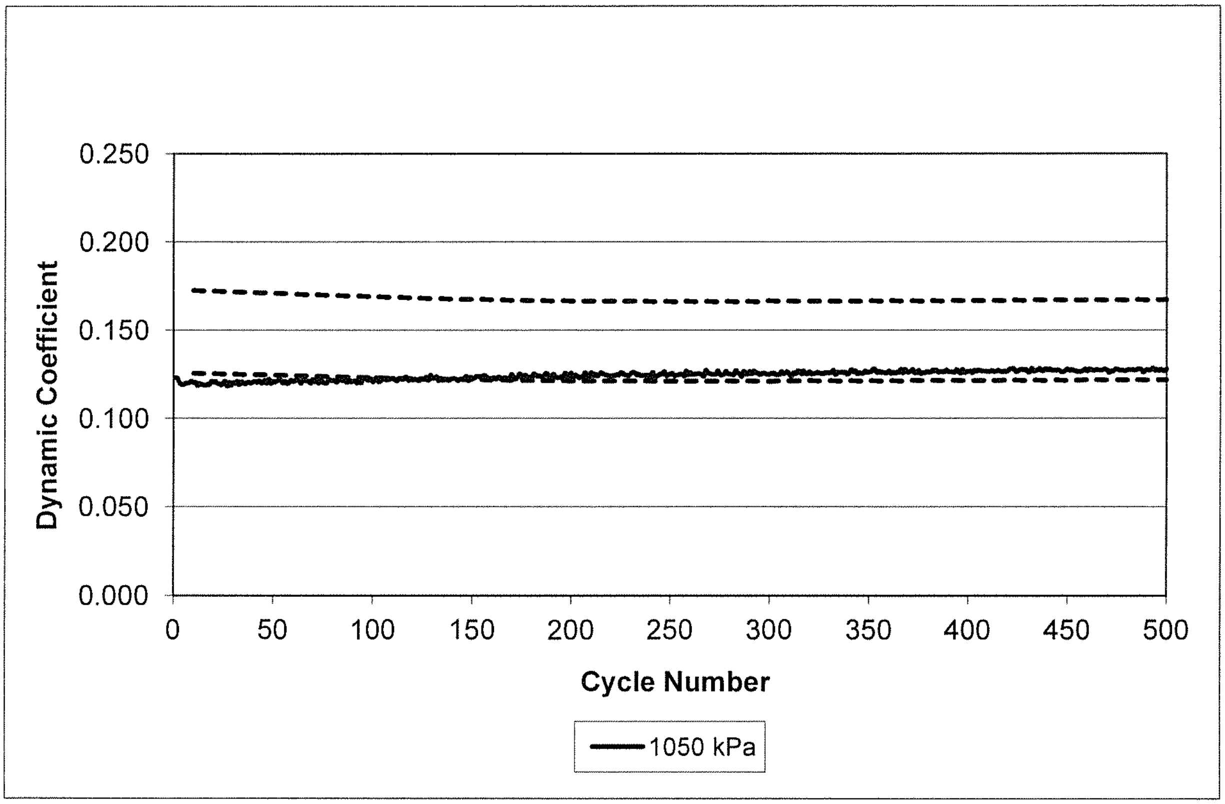
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	

Disc name & desc:	1Y0711
Material:	WHEEL BRAKE PAPER
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	06MR928188
Remarks:	

Plate Name & desc:	1Y0726
Surface:	0.26
Miscellaneous:	
Batch Number:	06MR928188
Remarks:	

Report limit name:	R-005-I
Limit file generated:	8/24/2012
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-134-I
Run: A-134-I
Started on: 4/10/2014 at 07:28:55

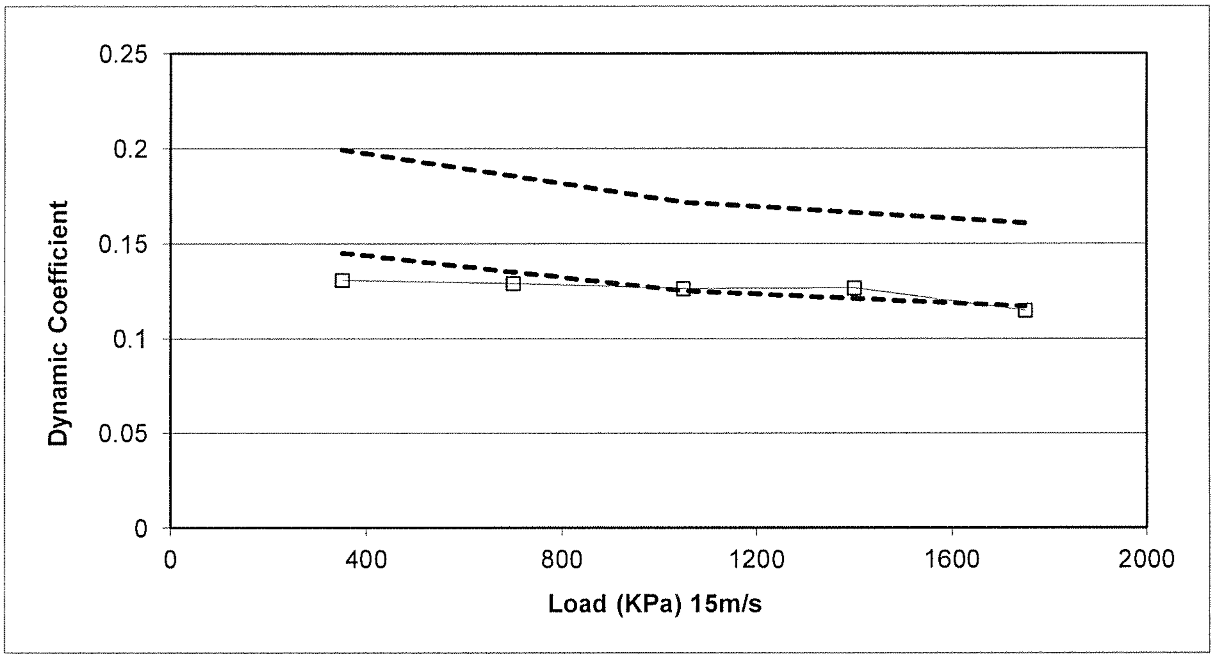


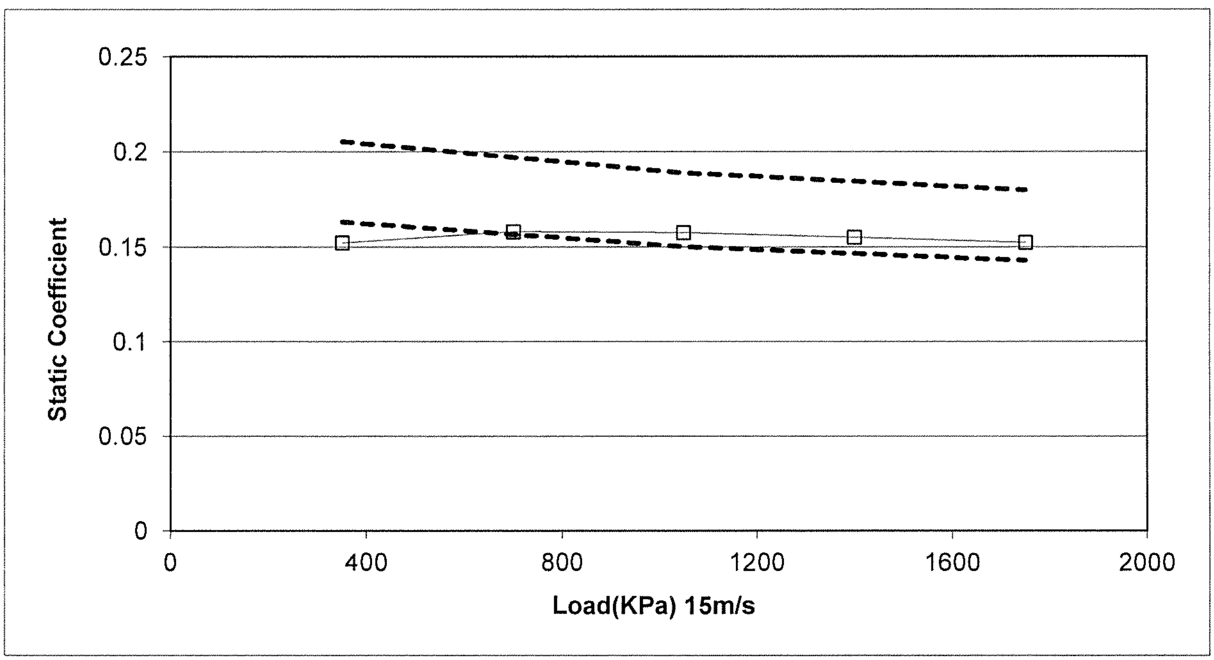
Wear Measurements
Thickness

Location	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
II	4.91	4.90	4.90	4.91	4.91	4.90
T	4.94	4.94	4.92	4.94	4.93	4.92
+	4.92	4.91	4.90	4.92	4.91	4.90
X	4.90	4.89	4.88	4.90	4.89	4.88
Y	4.90	4.89	4.88	4.90	4.89	4.88
Z	4.92	4.90	4.89	4.91	4.89	4.89
Average	4.92	4.91	4.89	4.91	4.90	4.89

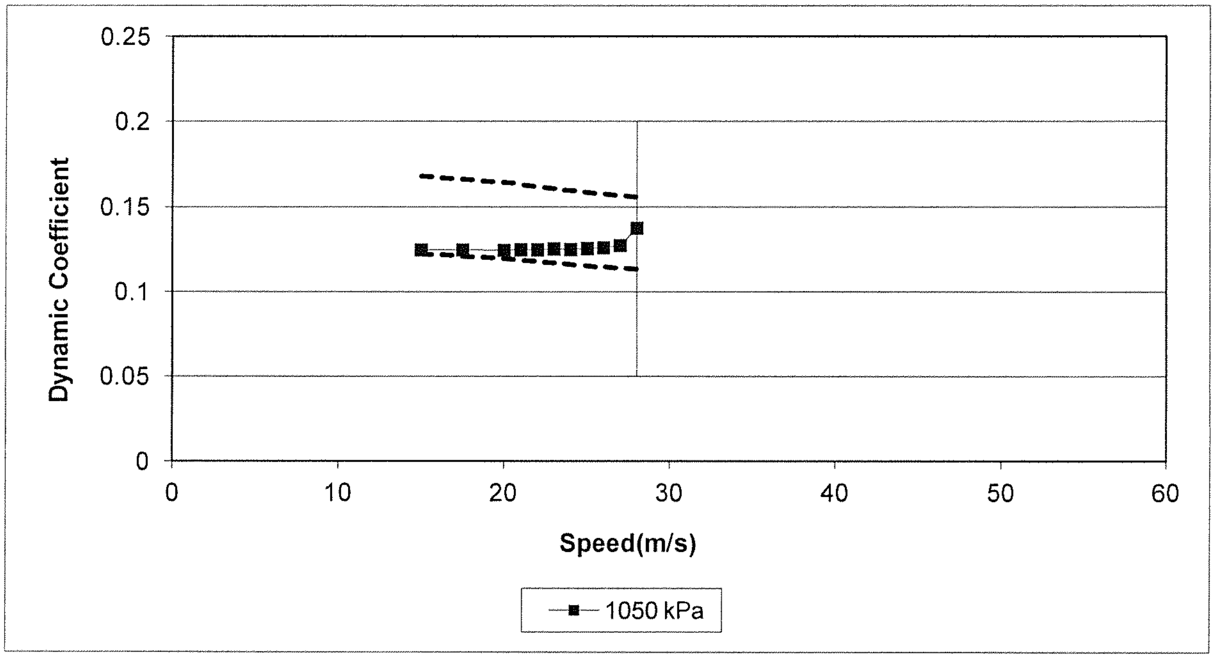
M1-M2 Compression set average wear: 0.010
M2-M3 average Wear: 0.010
Total Wear(all measurements in mm): 0.020

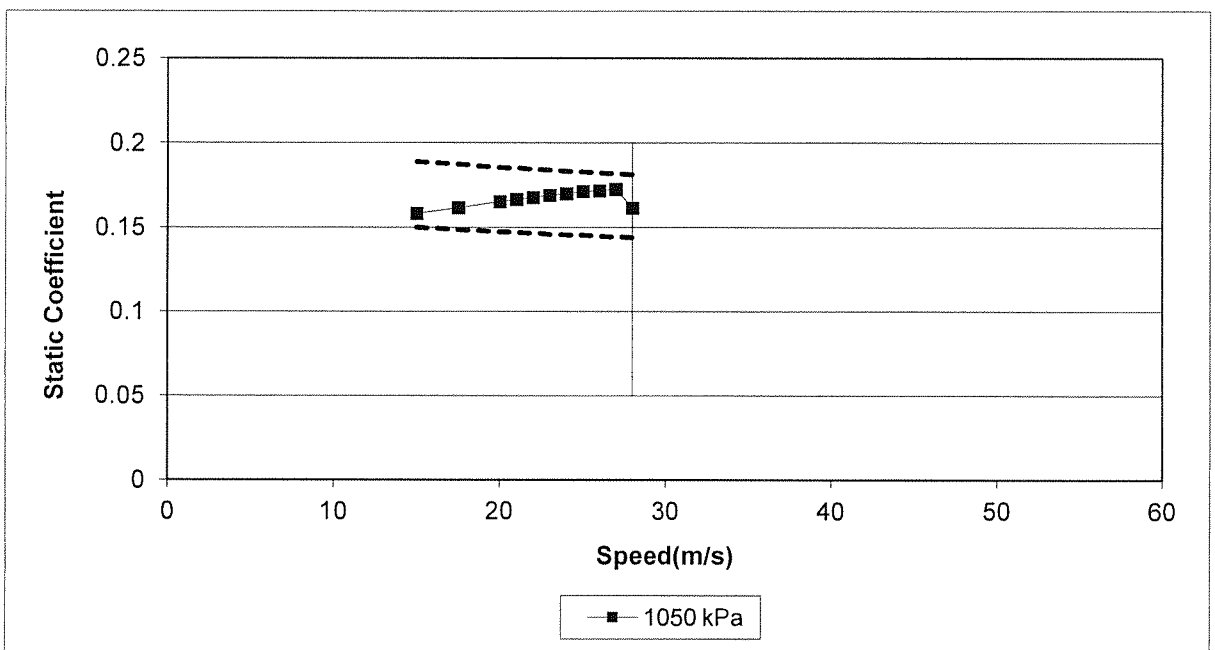
Test: A-134-I
Run: A-134-I
Started on: 4/10/2014 at 07:28:55



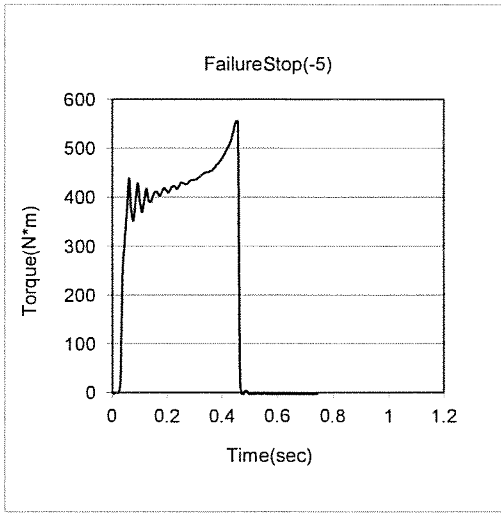


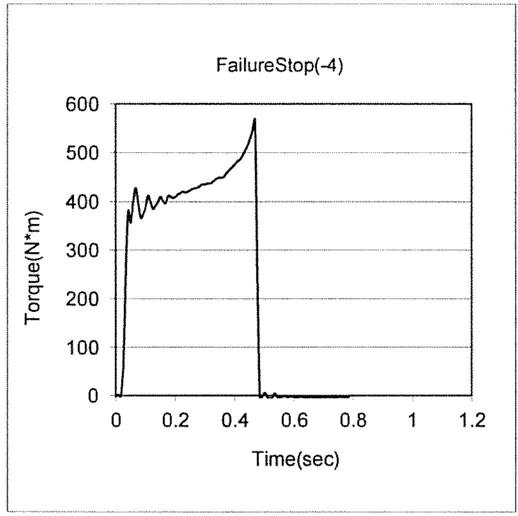
Test: A-134-I
Run: A-134-I
Started on: 4/10/2014 at 07:28:55

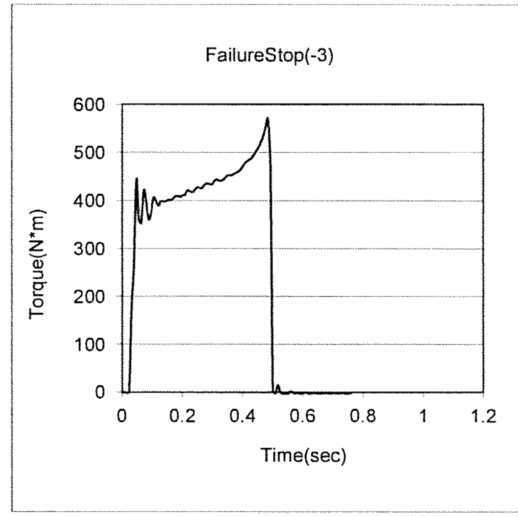


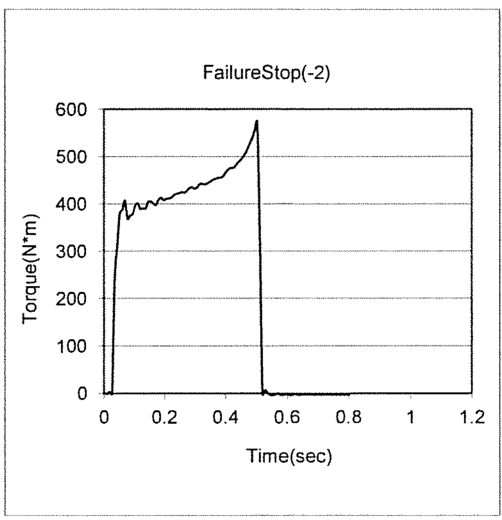


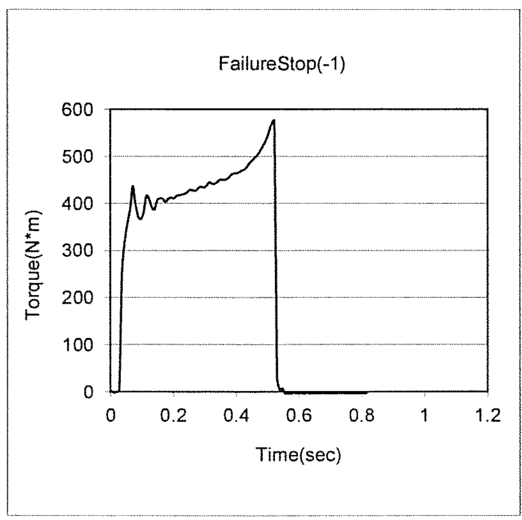
Test: A-134-I
Run: A-134-I
Started on: 4/10/2014 at 07:28:55

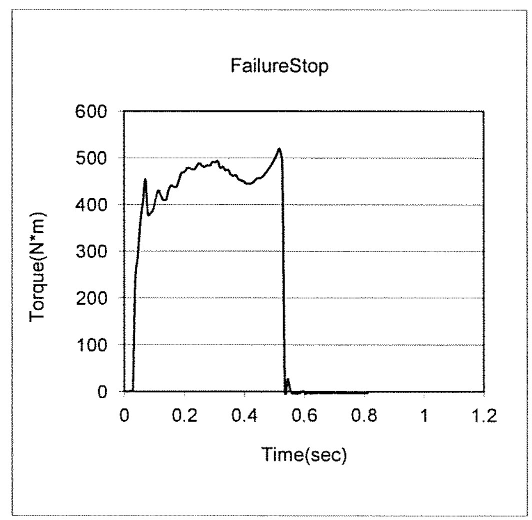












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San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70
FRRET SEQUENCE ONLY

Conducted for

ARMY LAB

Oil Code:
LO306520

Test Number:
A-135-I

April 15, 2014

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluation

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: 4/11/2014
End of test date: 4/15/2014
Oil Code: LO306520

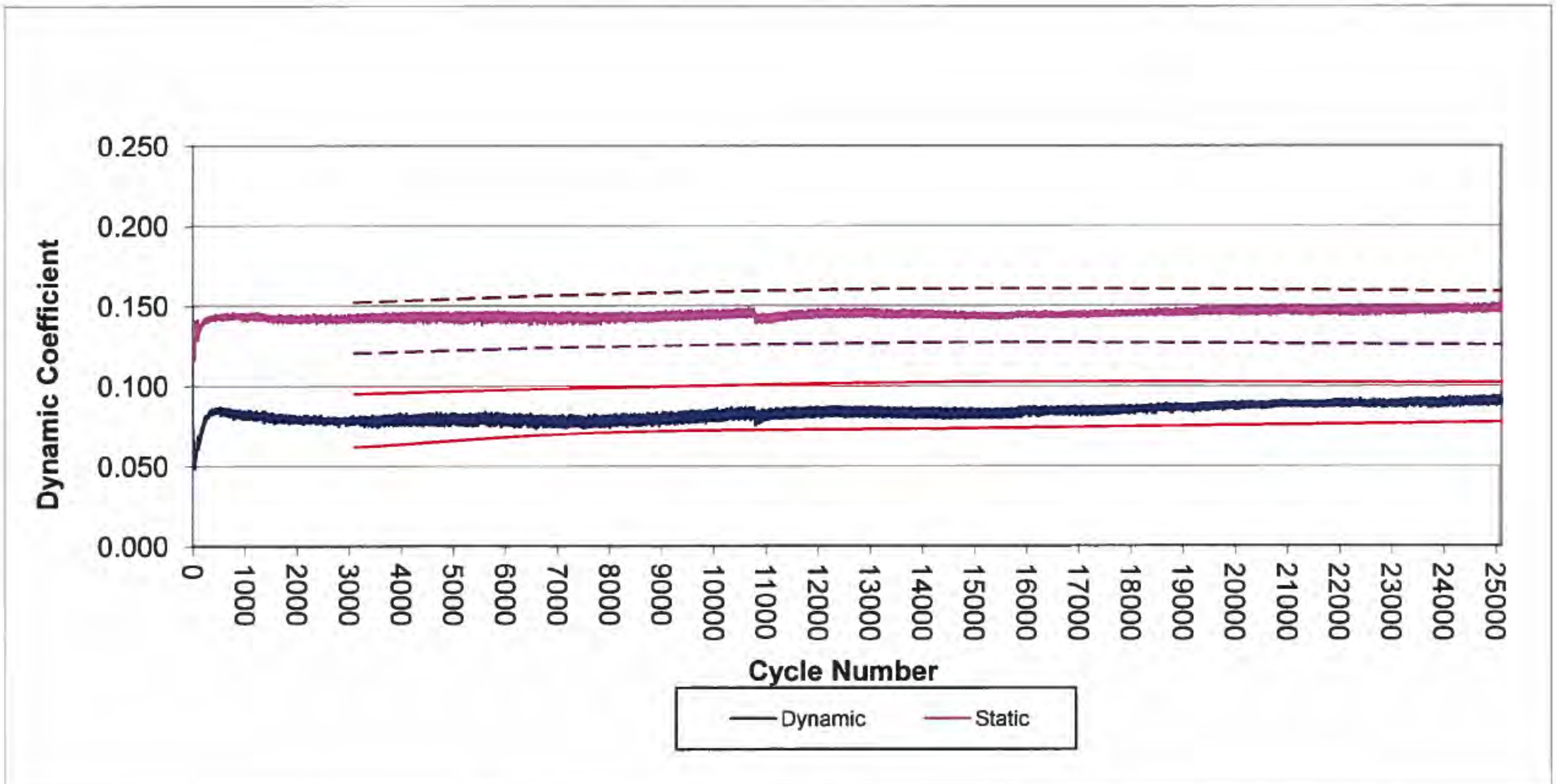
Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:							P
Dynamic Coefficient Vs. Load:							
Dynamic Coefficient Vs. Speed:							
Energy Limit:							
Static Coefficient Vs. Load:							
Static Coefficient Vs. Speed:							
Energy Limit:							
Total Wear:							
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand using 2009 batch parts. The results are compared to TO-4 testing limits.

P = Pass
N/A = Not Applicable

Test name:	A-135-I
Test date:	4/11/2014
Test description:	
Oil type:	LO306520
Viscosity:	SAE 30
Miscellaneous:	
Software version:	3.12
Run name & desc:	A-135-I
Run date:	4/11/2014
Oil temperature:	82
Oil flow rate:	4
Operator:	
Remarks:	
Sequence name:	FRRET
Remarks:	
Number of cylces run:	25100
Machine:	1131
Coast down check run:	
Result:(sec)	
Inertia check run:	
Result(n·m·s²):	
Disc name & desc:	1Y0709
Material:	SINTERED BRONZE
Groove pattern:	
Miscellaneous:	
Outer diameter(mm):	285.8008
Inner diameter(mm):	223.19996
Mean radius(mm):	128.2100001
Batch Number:	007130C800012
Remarks:	
Plate Name & desc:	1Y0726
Surface:	0.24
Miscellaneous:	
Batch Number:	007130C800012
Remarks:	
Report limit name:	R-008-I
Limit file generated:	9/14/2012
Report format name:	REPFRRET - FRICTION RETENTION

Test: A-135-I
Run: A-135-I
Started on: 04/11/2014 at 07:30:01



APPENDIX B.

Test Report, LO288074 MIL-PRF-2104H 15W40, DDC 6V53T High Temperature Evaluation

EVALUATION OF MIL-PRF-2104H AT HIGHT TEMPERATURE LO-288074

Project 14734.21

Detroit Diesel Corporation 6V53T

Test Lubricant: LO-288074
Test Fuel: JP8
Test Number: LO288074-6V53T1-T-240HT
Start of Test Date: July 19, 2013
End of Test Date: August 17, 2013
Test Duration: 240 Hours
Test Procedure: Tracked Vehicle Engine Cycle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of MIL-PRF-2104H (LO-288074) at high temperatures when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.21, Single Common Powertrain Lubricants for Combat/Tactical Equipment..

Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline below.
  -Immediately after run-in is complete, a no-load governor check is completed (2950-3030rpm). If engine governed speed is out of spec, adjust and retest.

Table 1 - Test Engine Run-In Procedure

Engine Speed [RPM]	Load [lb-ft]	Power (Observed) [bhp]	Duration [min]
1000	None commanded	--	10
2800	None commanded	--	30
1800	88	30	15
2200	310	130	30
2500	420	200	30
2800	422	225	30

- <u>Engine Shake Down:</u>
  -Engine operated for 5hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- <u>Pre Test Engine Powercurve:</u>
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- <u>Testing:</u>
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- <u>Post Test Engine Powercurve:</u>
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20hrs of operation followed by a 4hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table 2.

Table 2 - Test Cycle Operating Parameters

Parameter	Max Power	Max Torque	Idle
Speed [rpm]	2800 +/- 25	1600 +/- 25	850 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5	170 +/- 5
Inlet Fuel [°F]	100 +/- 5	100 +/- 5	100 +/- 5
Oil Sump [°F]	260 +/- 5	260 +/- 5	NS

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 sourced from a local fuel supplier. (Note: Oil sump specification of 260°F was for the Tracked Vehicle Cycle only. Engine run-in, shakedown, and powercurves were operated at nominally 220°F)

Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table 3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Table 3 - Used Oil Analysis Procedures

Daily Used Oil Analysis	
ASTM D445	Kinematic Viscosity @ 100°C
ASTM D5185	Wear Metals by ICP
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number

Used oil analysis results can be seen in the engine oil analysis section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

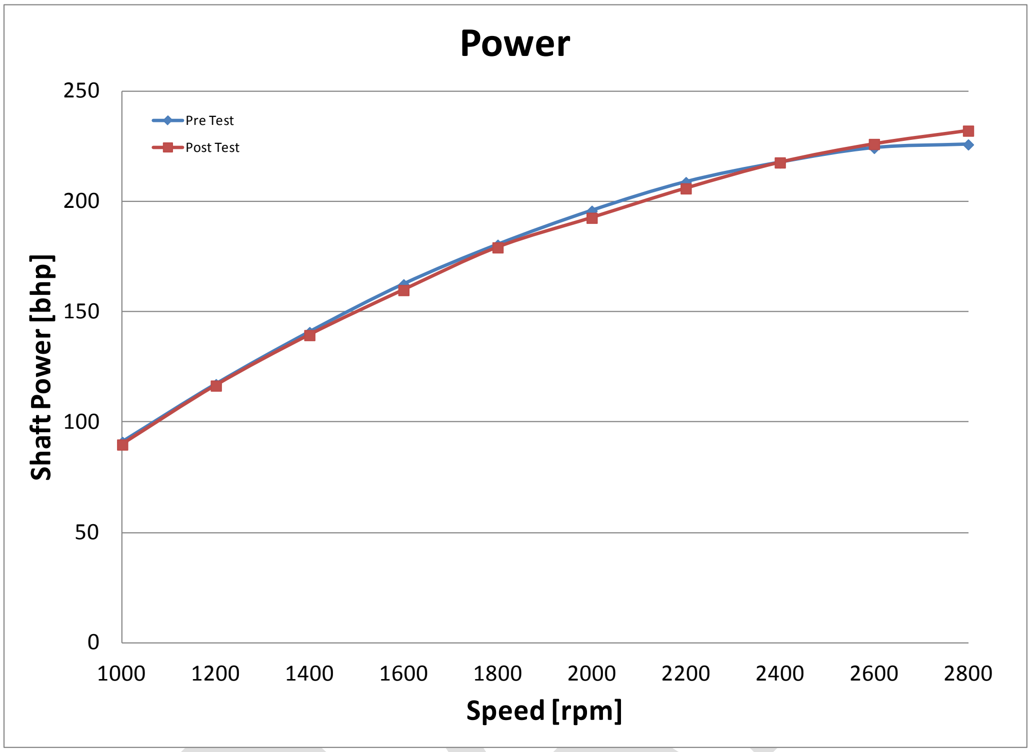
Engine Operating Conditions Summary

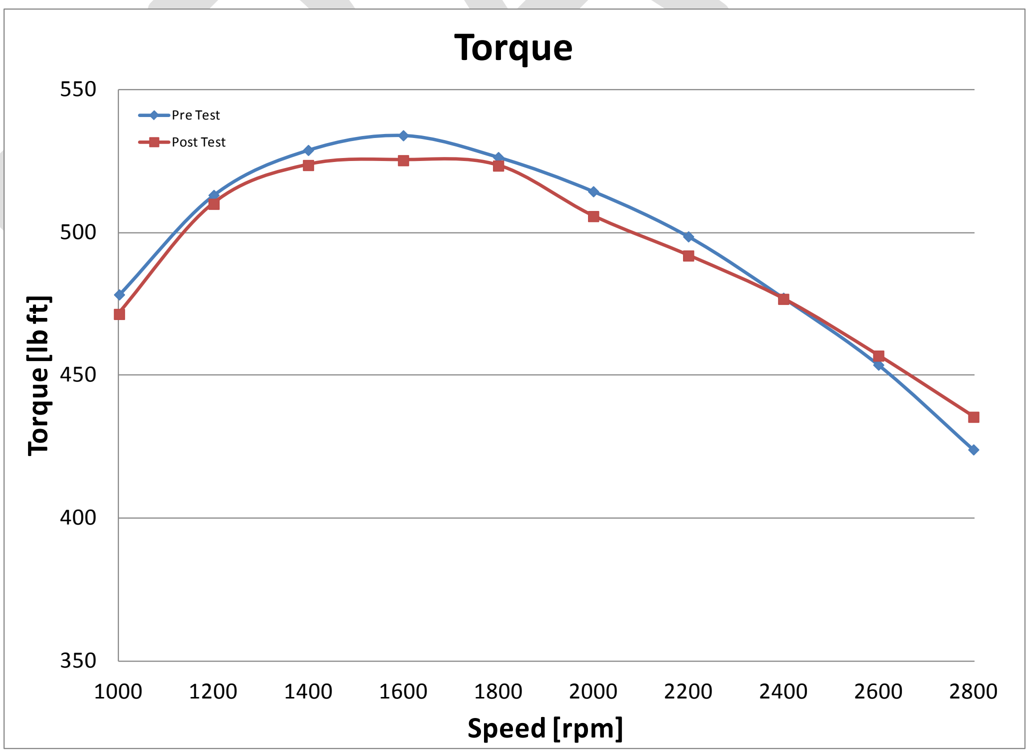
Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was completed by the lubricant. (Note: the engine operating summary was split into two segments, 0-100hrs and 100-240hrs, due to specific changes in the engines fuel system and overall power output observed during testing).

		Peak Power (2800 RPM) 0-100hrs		Peak Power (2800 RPM) **100-240hrs		Peak Torque (1600 RPM) 0-100hrs		Peak Torque (1600 RPM) **100-240hrs		Idle Conditions (850 RPM) 100-240hrs	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	2800.04	1.62	2800.02	0.87	1600.00	0.71	1600.02	0.66	854.89	20.65
Torque*	ft*lb	419.44	10.67	446.75	3.82	529.25	3.83	534.89	4.03	-	-
Fuel Flow	lb/hr	88.40	2.30	92.06	0.81	62.06	1.55	61.69	0.58	3.28	1.52
Power*	bhp	223.62	5.69	238.17	2.03	161.23	1.17	162.95	1.22	-	-
BSFC*	lb/bhp*hr	0.395	0.010	0.387	0.003	0.385	0.008	0.379	0.003	-	-
Engine Blowby	acfm	8.37	1.65	7.38	1.07	6.48	0.65	7.06	1.07	4.94	1.15
Temperatures:											
Coolant In	°F	161.56	0.72	161.16	0.69	158.99	0.73	158.70	0.69	163.90	8.12
Coolant Out	°F	170.00	0.64	170.00	0.52	169.98	0.64	169.99	0.56	166.53	8.47
Oil Galley	°F	234.88	10.86	234.35	12.23	247.32	6.51	247.08	8.20	210.52	21.27
Oil Sump	°F	259.99	1.53	260.02	1.31	260.04	0.99	260.00	1.29	211.98	21.46
Fuel In	°F	100.01	0.45	100.11	0.47	100.03	0.49	100.03	0.44	99.63	1.34
Dry Bulb	°F	94.46	6.28	95.75	6.07	93.05	6.84	94.06	6.88	92.46	6.45
Intake Air	°F	86.63	3.44	86.85	3.05	86.57	2.72	86.58	2.59	83.81	2.25
Air After Turbo	°F	260.31	3.47	271.55	5.34	192.81	2.70	195.75	3.25	91.80	3.50
Air After Supercharger	°F	261.33	4.23	269.59	4.75	198.20	2.06	202.36	3.37	154.12	16.35
Cylinder 1R Exhaust	°F	834.53	76.41	831.07	25.24	636.93	7.44	632.12	16.96	211.55	21.66
Cylinder 2R Exhaust	°F	829.60	5.47	846.33	29.19	730.90	5.99	724.92	7.57	183.19	17.57
Cylinder 3R Exhaust	°F	821.90	5.51	842.14	12.05	698.95	5.32	701.82	13.20	189.43	14.73
Cylinder 1L Exhaust	°F	829.30	8.43	875.04	21.90	667.96	7.14	712.42	18.70	205.91	15.11
Cylinder 2L Exhaust	°F	922.39	9.02	929.24	20.93	915.27	7.75	914.61	23.11	224.67	16.19
Cylinder 3L Exhaust	°F	858.28	18.18	911.23	17.05	842.62	20.21	863.29	19.54	204.04	17.54
Exhaust Exit Left	°F	892.77	9.97	925.46	15.36	875.00	8.94	883.96	17.99	215.19	16.71
Exhaust Exit Right	°F	867.85	6.04	830.60	14.35	796.77	5.46	734.31	15.33	185.92	15.54
Exhaust After Turbo	°F	708.21	7.20	722.67	18.07	717.74	8.37	716.48	17.73	219.33	24.84
Pressures:											
Oil Galley	psiG	45.58	0.93	45.93	0.92	27.25	0.58	27.71	0.67	17.40	4.11
Crankcase Pressure	inH20	0.21	0.04	0.28	0.04	0.06	0.03	0.07	0.02	0.02	0.03
Ambient Pressure	psiA	14.36	0.02	14.36	0.03	14.36	0.02	14.36	0.03	14.36	0.03
Pressure After Turbo	psiG	16.05	0.26	17.24	0.49	8.96	0.13	9.19	0.19	0.24	0.04
Pressure After Supercharger	psiG	17.66	0.29	18.82	0.36	8.27	0.15	8.51	0.17	0.36	0.09
Pressure Exhaust Left	psiG	15.36	0.23	16.40	0.27	7.67	0.11	7.87	0.14	0.13	0.06
Pressure Exhaust Right	psiG	14.47	0.21	15.49	0.26	7.22	0.09	7.44	0.12	0.13	0.04
Pressure Exhaust After Turbo	psiG	0.74	0.03	0.83	0.12	0.05	0.02	0.08	0.05	-0.02	0.00
Fuel Pressure	psiG	28.82	1.66	64.73	0.45	12.26	0.83	53.56	0.89	21.57	1.02

* Non-corrected Values, ** Calculations exclude test hours 176.5 though 185.5 due to a malfunctinoing 1R injector

Engine Performance Curves

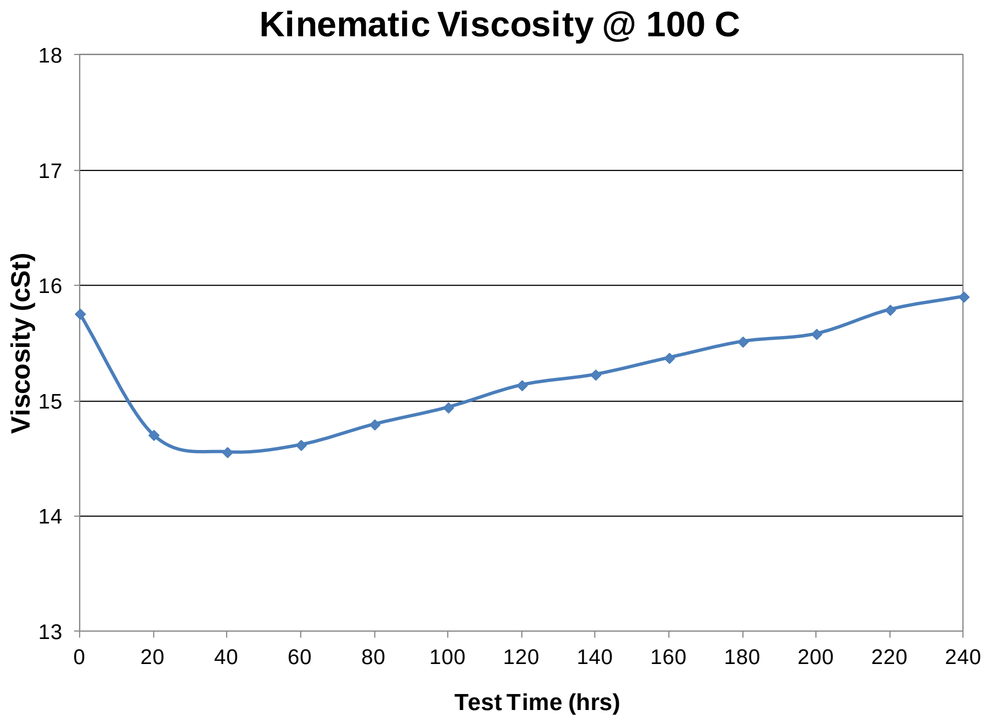


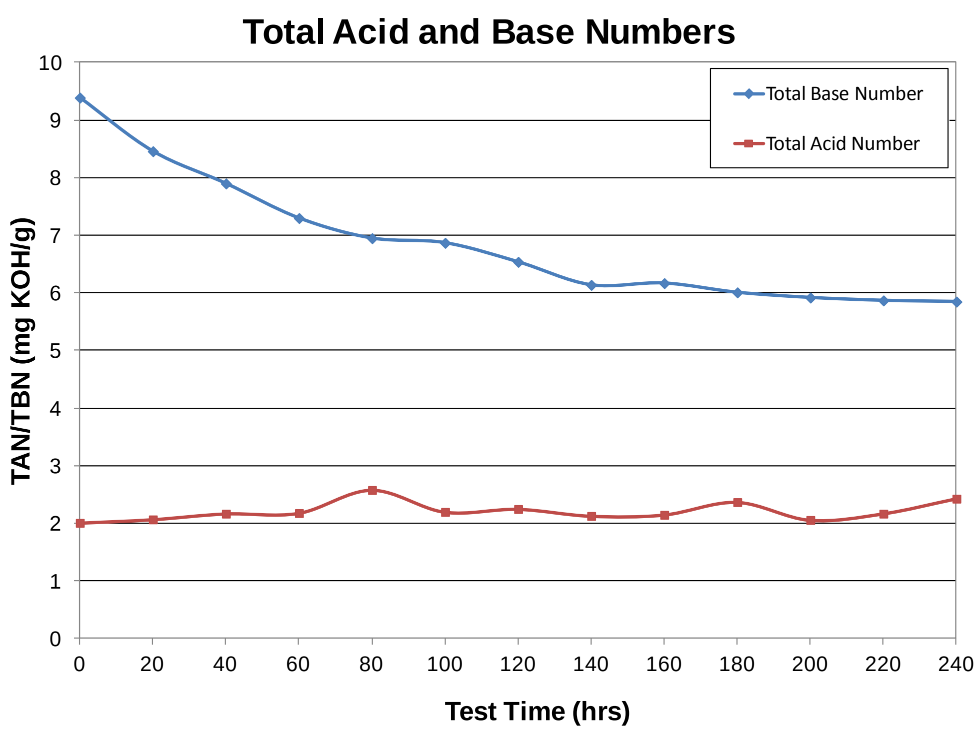


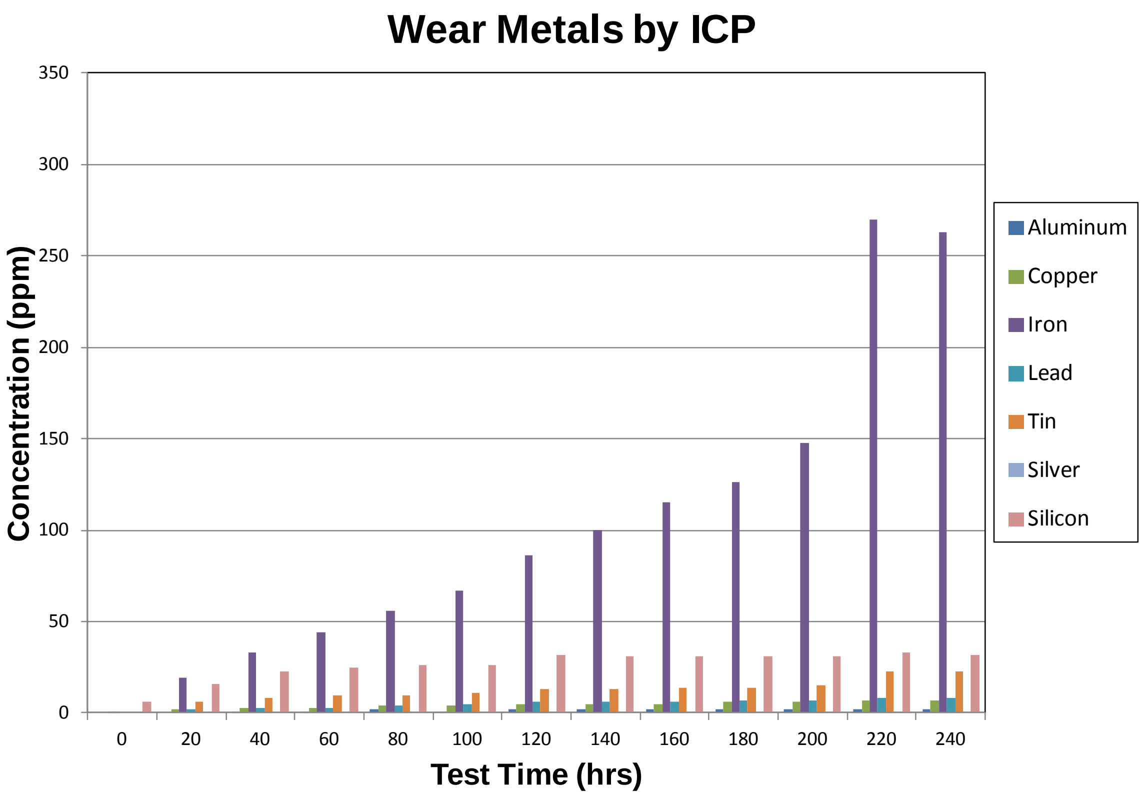
Engine Oil Analysis

Property	ASTM Test	Test Hours												
		0	20	40	60	80	100	120	140	160	180	200	220	240
Viscosity @ 100°C (cSt)	D445	15.8	14.7	14.6	14.6	14.8	14.9	15.1	15.2	15.4	15.5	15.6	15.8	15.9
Total Base Number (mg KOH/g)	D4739	9.4	8.5	7.9	7.3	7.0	6.9	6.5	6.1	6.2	6.0	5.9	5.9	5.9
Total Acid Number (mg KOH/g)	D664	2.0	2.1	2.2	2.2	2.6	2.2	2.3	2.1	2.2	2.4	2.1	2.2	2.4
Wear Metals (ppm)	D5185													
Al		<1	<1	1	1	2	1	2	2	2	2	2	2	2
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		<1	<1	<1	<1	<1	1	<1	<1	<1	2	1	1	2
Ca		2391	2429	2483	2460	2555	2516	2512	2604	2543	2636	2666	2710	2620
Cr		<1	<1	2	2	2	3	3	3	4	4	4	6	6
Cu		<1	2	3	3	4	4	5	5	5	6	6	7	7
Fe		1	19	33	44	56	67	86	100	115	126	148	270	263
Pb		<1	2	3	3	4	5	6	6	6	7	7	8	8
Mg		294	303	313	316	322	319	321	327	320	329	333	337	324
Mn		<1	<1	<1	<1	<1	1	1	1	2	2	2	3	3
Mo		<1	2	3	4	4	5	6	7	8	9	10	18	17
Ni		<1	<1	<1	<1	<1	<1	<1	1	1	1	1	3	3
P		1330	1297	1287	1246	1221	1230	1228	1221	1202	1215	1202	1220	1213
Si		6	16	23	25	26	26	32	31	31	31	31	33	32
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	5	6	6	6	6	9	10	14	10	10	9	9
Sn		<1	6	8	10	10	11	13	13	14	14	15	23	23
Zn		1418	1408	1415	1402	1423	1407	1419	1425	1423	1448	1457	1487	1460
K		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Engine Oil Analysis Trends







Wear Metals by ICP
Concentration (ppm)
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.180 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
20 hr		0.17	-0.17	-0.17
40 hr	3.19	0.18	3.01	2.84
60 hr	3.43	0.18	3.25	6.09
80 hr	3.53	0.19	3.34	9.43
100 hr	4.32	0.19	4.13	13.56
120 hr	4.14	0.24	3.9	17.46
140 hr	3.13	0.2	2.93	20.39
160 hr	2.9	0.19	2.71	23.1
180 hr	3.19	0.19	3	26.1
200 hr	4.12	0.19	3.93	30.03
220 hr	3.1	0.19	2.91	32.94
240 hr	2.6	0.19	2.41	35.35
	Initial Fill	40.74	**Total Additions**	37.65
	EOT Drain	32.99	**Total Samples**	2.3

(Initial Fill + Additions)	78.39
(EOT Drain + Samples)	35.29
Total Oil Consumption	43.1

Engine Measurements

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8770	3.8758		0.0012
	25mm Above Port	3.8767	3.8758	3.8763	0.0009
	25mm Below Port	3.8764	3.8758		0.0006
	13mm From Bottom	3.8762	3.8765		0.0003
	Taper	0.0008	0.0007		
2L	13mm From Top	3.8764	3.8762		0.0002
	25mm Above Port	3.8758	3.8757	3.8760	0.0001
	25mm Below Port	3.8758	3.8757		0.0001
	13mm From Bottom	3.8758	3.8764		0.0006
	Taper	0.0006	0.0007		
3L	13mm From Top	3.8760	3.8758		0.0002
	25mm Above Port	3.8757	3.8757	3.8758	0.0000
	25mm Below Port	3.8755	3.8756		0.0001
	13mm From Bottom	3.8757	3.8760		0.0003
	Taper	0.0005	0.0004		
1R	13mm From Top	3.8756	3.8764		0.0008
	25mm Above Port	3.8756	3.8761	3.8759	0.0005
	25mm Below Port	3.8756	3.8759		0.0003
	13mm From Bottom	3.8758	3.8759		0.0001
	Taper	0.0002	0.0005		
2R	13mm From Top	3.8768	3.8761		0.0007
	25mm Above Port	3.8762	3.8760	3.8762	0.0002
	25mm Below Port	3.8760	3.8760		0.0000
	13mm From Bottom	3.8761	3.8763		0.0002
	Taper	0.0008	0.0003		
3R	13mm From Top	3.8763	3.8760		0.0003
	25mm Above Port	3.8760	3.8758	3.8760	0.0002
	25mm Below Port	3.8757	3.8757		0.0000
	13mm From Bottom	3.8764	3.8759		0.0005
	Taper	0.0007	0.0003		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8776	3.8764		0.0012
	25mm Above Port	3.8767	3.8762	3.8767	0.0005
	25mm Below Port	3.8770	3.8763		0.0007
	13mm From Bottom	3.8762	3.8772		0.0010
	Taper	0.0014	0.0010		
2L	13mm From Top	3.8771	3.8762		0.0009
	25mm Above Port	3.8761	3.8759	3.8764	0.0002
	25mm Below Port	3.8769	3.8761		0.0008
	13mm From Bottom	3.8757	3.8770		0.0013
	Taper	0.0014	0.0011		
3L	13mm From Top	3.8766	3.8763		0.0003
	25mm Above Port	3.8760	3.8759	3.8762	0.0001
	25mm Below Port	3.8760	3.8761		0.0001
	13mm From Bottom	3.8765	3.8759		0.0006
	Taper	0.0006	0.0004		
1R	13mm From Top	3.8760	3.8768		0.0008
	25mm Above Port	3.8760	3.8764	3.8763	0.0004
	25mm Below Port	3.8763	3.8763		0.0000
	13mm From Bottom	3.8762	3.8763		0.0001
	Taper	0.0003	0.0005		
2R	13mm From Top	3.8822	3.8772		0.0050
	25mm Above Port	3.8811	3.8782	3.8783	0.0029
	25mm Below Port	3.8773	3.8768		0.0005
	13mm From Bottom	3.8763	3.8773		0.0010
	Taper	0.0059	0.0014		
3R	13mm From Top	3.8772	3.8768		0.0004
	25mm Above Port	3.8768	3.8765	3.8769	0.0003
	25mm Below Port	3.8773	3.8766		0.0007
	13mm From Bottom	3.8763	3.8775		0.0012
	Taper	0.0010	0.0010		

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA Change	Out of Round
1L	13mm From Top	0.0006	0.0006		0.0000
	25mm Above Port	0.0000	0.0004	0.0004	0.0004
	25mm Below Port	0.0006	0.0005		0.0001
	13mm From Bottom	0.0000	0.0007		0.0007
	Taper	0.0006	0.0003		
2L	13mm From Top	0.0007	0.0000		0.0007
	25mm Above Port	0.0003	0.0002	0.0004	0.0001
	25mm Below Port	0.0011	0.0004		0.0007
	13mm From Bottom	0.0001	0.0006		0.0007
	Taper	0.0010	0.0006		
3L	13mm From Top	0.0006	0.0005		0.0001
	25mm Above Port	0.0003	0.0002	0.0004	0.0001
	25mm Below Port	0.0005	0.0005		0.0000
	13mm From Bottom	0.0008	0.0001		0.0003
	Taper	0.0005	0.0004		
1R	13mm From Top	0.0004	0.0004		0.0000
	25mm Above Port	0.0004	0.0003	0.0004	0.0001
	25mm Below Port	0.0007	0.0004		0.0003
	13mm From Bottom	0.0004	0.0004		0.0000
	Taper	0.0003	0.0001		
2R	13mm From Top	0.0054	0.0011		0.0043
	25mm Above Port	0.0049	0.0022	0.0021	0.0027
	25mm Below Port	0.0013	0.0008		0.0005
	13mm From Bottom	0.0002	0.0010		0.0008
	Taper	0.0052	0.0014		
3R	13mm From Top	0.0009	0.0008		0.0001
	25mm Above Port	0.0008	0.0007	0.0009	0.0001
	25mm Below Port	0.0016	0.0009		0.0007
	13mm From Bottom	0.0001	0.0016		0.0007
	Taper	0.0015	0.0009		
Avgerage All Cylinders	13mm From Top	0.0006	0.0005		
	25mm Above Port	0.0004	0.0004		
	25mm Below Port	0.0009	0.0005		
	13mm From Bottom	0.0003	0.0007		

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Pre-Test Liner Surface Finish, µm

Pre Test Liner Surface Finish, µm					
1L	2L	3L	1R	2R	3R
1.11	1.11	1.17	1.04	1.08	1.09

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1L	3.8763	3.8711	0.0052
	2L	3.8760	3.8709	0.0051
	3L	3.8758	3.8718	0.0040
	1R	3.8759	3.8709	0.0050
	2R	3.8762	3.8718	0.0044
	3R	3.8760	3.8717	0.0043
Post - Test	1L	3.8767	3.8705	0.0062
	2L	3.8764	3.8695	0.0069
	3L	3.8762	3.8696	0.0066
	1R	3.8763	3.8691	0.0072
	2R	3.8783	3.8693	0.0090
	3R	3.8769	3.8694	0.0075

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Connecting Rod Bearing Mass Change, grams

Rod Bearing	Shell	Before	After	Change
1L	Top	73.1788	73.1537	0.0251
	Bottom	68.6177	68.6134	0.0043
2L	Top	73.0096	72.9887	0.0209
	Bottom	69.3075	69.3039	0.0036
3L	Top	73.2129	73.1957	0.0172
	Bottom	69.2610	69.2566	0.0044
1R	Top	73.2830	73.2661	0.0169
	Bottom	68.6040	68.5989	0.0051
2R	Top	73.3814	73.3665	0.0149
	Bottom	68.6161	68.6125	0.0036
3R	Top	73.3375	73.3228	0.0147
	Bottom	68.6525	68.6482	0.0043

Maximum	0.0251
Average	0.0113

Slipper Bushing Mass Change, grams

Slipper Bushing	Before	After	Change
1L	56.2584	56.0955	0.1629
2L	56.2142	56.1318	0.0824
3L	56.2198	56.1094	0.1104
1R	56.0169	55.8921	0.1248
2R	56.0578	55.8956	0.1622
3R	55.8182	55.6772	0.1410

Maximum	0.1629
Average	0.1306

Pre-Test Slipper Bushing Tin Plate Thickness, inches

Slipper Bushing Tin Plate Thickness					
1L	2L	3L	1R	2R	3R
0.02135	0.02045	0.02095	0.02045	0.02030	0.02100

Top, Second, and Third Ring Radial Measurements, inches

Top Ring				
Cylinder	**Position**	**Before**	**After**	**Delta**
1L	1	0.15485	0.15415	0.00070
	2	0.15475	0.15440	0.00035
	3	0.15495	0.15465	0.00030
	4	0.15415	0.15370	0.00045
	5	0.15520	0.15425	0.00095
2L	1	0.15655	0.15590	0.00065
	2	0.15650	0.15640	0.00010
	3	0.15570	0.15555	0.00015
	4	0.15550	0.15545	0.00005
	5	0.15580	0.15525	0.00055
3L	1	0.15875	0.15815	0.00060
	2	0.15965	0.15955	0.00010
	3	0.15920	0.15920	0.00000
	4	0.15780	0.15770	0.00010
	5	0.15880	0.15820	0.00060
1R	1	0.15675	0.15600	0.00075
	2	0.15610	0.15570	0.00040
	3	0.15765	0.15740	0.00025
	4	0.15800	0.15780	0.00020
	5	0.15770	0.15660	0.00110
2R	1	0.15335	0.14985	0.00350
	2	0.15500	0.15310	0.00190
	3	0.15665	0.15495	0.00170
	4	0.15585	0.15410	0.00175
	5	0.15375	0.14940	0.00435
3R	1	0.15405	0.15335	0.00070
	2	0.15510	0.15455	0.00055
	3	0.15460	0.15435	0.00025
	4	0.15500	0.15500	0.00000
	5	0.15295	0.15210	0.00085

***Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error**

Maximum	0.00110
Average	0.00043

Second Ring				
Cylinder	**Position**	**Before**	**After**	**Delta**
1L	1	0.14830	0.14580	0.00250
	2	0.14790	0.14676	0.00114
	3	0.14690	0.14620	0.00070
	4	0.14655	0.14590	0.00065
	5	0.14770	0.14635	0.00135
2L	1	0.14755	0.14685	0.00070
	2	0.14760	0.14720	0.00040
	3	0.14615	0.14545	0.00070
	4	0.14540	0.14475	0.00065
	5	0.14720	0.14635	0.00085
3L	1	0.14655	0.14570	0.00085
	2	0.14780	0.14700	0.00080
	3	0.14715	0.14645	0.00070
	4	0.14755	0.14690	0.00065
	5	0.14690	0.14620	0.00070
1R	1	0.14820	0.14735	0.00085
	2	0.14670	0.14625	0.00045
	3	0.14810	0.14735	0.00075
	4	0.14885	0.14815	0.00070
	5	0.14850	0.14775	0.00075
2R	1	0.14650	0.14325	0.00325
	2	0.14635	0.14070	0.00565
	3	0.14525	0.13690	0.00835
	4	0.14755	0.14308	0.00447
	5	0.14755	0.14415	0.00340
3R	1	0.14910	0.14830	0.00080
	2	0.14865	0.14800	0.00065
	3	0.14730	0.14655	0.00075
	4	0.14815	0.14740	0.00075
	5	0.14835	0.14755	0.00080

***Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error**

Maximum	0.00250
Average	0.00082

Third Ring				
Cylinder	**Position**	**Before**	**After**	**Delta**
1L	1	0.14770	0.14680	0.00090
	2	0.14760	0.14590	0.00170
	3	0.14700	0.14660	0.00040
	4	0.14920	0.14865	0.00055
	5	0.14815	0.14725	0.00090
2L	1	0.14750	0.14725	0.00025
	2	0.14770	0.14740	0.00030
	3	0.14645	0.14610	0.00035
	4	0.14535	0.14490	0.00045
	5	0.14710	0.14660	0.00050
3L	1	0.14750	0.14710	0.00040
	2	0.14725	0.14690	0.00035
	3	0.14725	0.14690	0.00035
	4	0.14690	0.14650	0.00040
	5	0.14690	0.14630	0.00060
1R	1	0.14825	0.14775	0.00050
	2	0.14845	0.14805	0.00040
	3	0.14835	0.14800	0.00035
	4	0.14765	0.14715	0.00050
	5	0.14820	0.14765	0.00055
2R	1	0.14630	0.14395	0.00235
	2	0.14605	0.14325	0.00280
	3	0.14515	0.14185	0.00330
	4	0.14750	0.14460	0.00290
	5	0.14715	0.14470	0.00245
3R	1	0.14785	0.14725	0.00060
	2	0.14870	0.14825	0.00045
	3	0.14935	0.14885	0.00050
	4	0.14750	0.14695	0.00055
	5	0.14710	0.14670	0.00040

***Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error**

Maximum	0.00170
Average	0.00053

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Increase
1L	1	0.029	0.031	0.002
	2	0.031	0.036	0.005
	3	0.030	0.034	0.004
	4	0.016	0.024	0.008
	5a	0.016	0.020	0.004
	5b	0.015	0.017	0.002
2L	1	0.030	0.034	0.004
	2	0.030	0.033	0.003
	3	0.029	0.031	0.002
	4	0.019	0.025	0.006
	5a	0.015	0.019	0.004
	5b	0.015	0.019	0.004
3L	1	0.030	0.032	0.002
	2	0.031	0.034	0.003
	3	0.031	0.033	0.002
	4	0.015	0.021	0.006
	5a	0.016	0.019	0.003
	5b	0.016	0.019	0.003
1R	1	0.030	0.032	0.002
	2	0.030	0.033	0.003
	3	0.030	0.031	0.001
	4	0.015	0.020	0.005
	5a	0.015	0.018	0.003
	5b	0.016	0.019	0.003
2R	1	0.032	0.043	0.011
	2	0.031	0.062	0.031
	3	0.032	0.048	0.016
	4	0.016	0.021	0.005
	5a	0.015	0.020	0.005
	5b	0.015	0.021	0.006
3R	1	0.038	0.039	0.001
	2	0.030	0.033	0.003
	3	0.030	0.032	0.002
	4	0.015	0.021	0.006
	5a	0.015	0.019	0.004
	5b	0.015	0.019	0.004

Ring No. 1 max increase	0.004
Ring No. 2 max increase	0.005
Ring No. 3 max increase	0.004
Ring No. 4 max increase	0.008
Ring No. 5a max increase	0.004
Ring No. 5b max increase	0.004

Ring No. 1 avg increase	0.002
Ring No. 2 avg increase	0.003
Ring No. 3 avg increase	0.002
Ring No. 4 avg increase	0.006
Ring No. 5a avg increase	0.004
Ring No. 5b avg increase	0.003

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Piston Ring Mass Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1L	1	22.8309	22.8131	0.0178
	2	20.1595	20.0624	0.0971
	3	20.2289	20.1691	0.0598
	4	27.8405	27.8229	0.0176
	5	24.4568	24.4316	0.0252
2L	1	23.0771	23.0698	0.0073
	2	20.0362	20.0023	0.0339
	3	20.0377	20.0258	0.0119
	4	27.7761	27.7589	0.0172
	5	24.2955	24.2698	0.0257
3L	1	23.3764	23.3715	0.0049
	2	20.1341	20.0915	0.0426
	3	20.1234	20.1094	0.0140
	4	27.7136	27.6974	0.0162
	5	23.8705	23.8511	0.0194
1R	1	23.2091	23.1894	0.0197
	2	20.2566	20.2088	0.0478
	3	20.2776	20.2575	0.0201
	4	27.7519	27.7349	0.0170
	5	24.2084	24.1864	0.0220
2R	1	22.9773	22.8662	0.1111
	2	19.9967	19.2233	0.7734
	3	19.9687	19.6156	0.3531
	4	27.6805	27.6570	0.0235
	5	24.0866	24.0499	0.0367
3R	1	23.0134	23.0091	0.0043
	2	20.2398	20.1968	0.0430
	3	20.2546	20.2354	0.0192
	4	27.8999	27.8729	0.0270
	5	24.2062	24.1721	0.0341

Ring No. 1 max decrease	0.0197
Ring No. 2 max decrease	0.0971
Ring No. 3 max decrease	0.0598
Ring No. 4 max decrease	0.0270
Ring No. 5 max decrease	0.0341

Ring No. 1 avg decrease	0.0108
Ring No. 2 avg decrease	0.0529
Ring No. 3 avg decrease	0.0250
Ring No. 4 avg decrease	0.0190
Ring No. 5 avg decrease	0.0253

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

Oil Control & Expander Ring Tension, pounds

	Oil Control & Expander Ring Tension					
	1L	2L	3L	1R	2R	3R
Top Oil Ring	10.1	10.7	12.1	10	10.8	10.8
Second Oil Ring	11.4	10.9	12.2	10.7	10.9	11.4

NOTE – To be used as reference only.
Measurements taken with uncalibrated legacy equipment.

Post Test Engine Ratings

Piston Ratings, Demerits

Ratings	Cylinder Number						
	1L	2L	3L	1R	2R	3R	**Avg**
Ring Sticking (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference)							
Top	F (25%CP)	F (25%CP)	F (25%CP)	F (25%CP)	F (50%CP)	F (25%CP)	--
Second	F	F	F	F	F (5%CP)	F	--
Third	F	F	F	F	F	F	--
Oil Control Rings	F	F	F	F	F	F	--
2nd Ring Carbon							
Heavy Carbon	0	85	20	75	0	49	--
Light Carbon	5	15	80	25	70	51	--
Piston Carbon, Demerits							
No.1 Groove	59.50	58.50	66.75	59.25	41.75	62.00	57.96
No.2 Groove	34.00	38.50	28.00	45.25	36.25	38.50	36.75
No.3 Groove	24.50	24.75	23.75	25.00	25.00	24.75	24.63
No.1 Land	34.75	40.75	37.75	51.25	30.25	39.25	39.00
No.2 Land	67.00	57.50	54.25	44.00	57.25	54.25	55.71
No.3 Land	16.25	27.50	27.25	23.25	34.00	21.25	24.92
No.4 Land	14.50	12.25	10.50	10.00	22.50	8.00	12.96
Piston Lacquer, Demerits							
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.3 Groove	0.00	0.03	0.00	0.00	0.00	0.00	0.01
No.1 Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Land	0.00	0.15	0.00	0.10	0.00	0.00	0.04
No.3 Land	0.66	0.55	1.05	1.11	0.00	0.63	0.67
No.4 Land	0.00	1.79	1.91	2.83	0.29	2.31	1.52
Total, Demerits	251.16	262.27	251.21	262.04	247.29	250.94	254.15
Miscellanous							
Top Groove Fill, %	69	62	80	57	38	60	61.00
Intermediate Groove Fill, %	57	46	65	66	57	51	57.00
Top Land Heavy Carbon, %	13	21	17	35	7	19	18.67
Top Land Flaked Carbon, %	0	0	0	0	0	0	0.00

Ring Face Distress, Demerits

Cylinder No.	Ring No.	Extreme Distress (1.00) % Area	Heavy Distress (0.75) % Area	Medium Distress (0.50) % Area	Light Distress (0.25) % Area	No Distress (0.00) % Area	Total Demerits
1L	1		9	8	39	44	0.205
	2					100	0
	3					100	0
2L	1			2	39	59	0.1075
	2				3	97	0.0075
	3					100	0
3L	1		2	4	11	83	0.0625
	2					100	0
	3					100	0
1R	1		8		13	79	0.0925
	2					100	0
	3					100	0
2R	1		70	20	10		0.65
	2			4	86	10	0.235
	3					100	0
3R	1		5		15	80	0.075
	2					100	0
	3					100	0

Piston Ring Face Distress	Fire Ring	2nd Ring	3rd Ring
Average Demerits	0.1085	0.0015	0.0000

Note: Liner 2R 45% scuffed at EOT. Liner results removed from overall results.

EOT Cylinder Liner Ratings, % Area

	Cylinder Liner Ratings					
	% Scuffing		Total % Area Scuffed	% Polish		Total % Area Polished
	T	AT		T	AT	
1L	0	1	1	0	8	8
2L	0	0	0	0	4	4
3L	0	0	0	2	2	4
1R	0	2	2	0	3	3
2R	45	45	90	3	4	7
3R	0	1	1	2	0	2
Percent of total ring travel area						

Periodic Bore Inspection Results, % Area

Periodic Bore Inspection, % Scuffed Area				
Cyl	**0hr**	**60hr**	**120hr**	**180hr**
1L	0	0	0	0
2L	0	0	0	0
3L	0	0	0	0
1R	0	0	0	0
2R	0	0	7	10
3R	0	0	0	0

Piston Skirt Ratings

	Piston Skirt Ratings	
	Thrust	Anti-Thrust
1L	Very Light Scratches	Few Light Scratches
2L	Light Scratches	Very Light Scratches
3L	Very Light to Trace Scratches	Trace to Light Scratches
1R	Very Light Scratches	Very Light Scratches
2R	Very Light Scratches	Light Scratches & 15% Scuffing
3R	Very Light Scratches	Very Light Scratches

EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

Intake Port Plugging	
1L	2
2L	0
3L	1
1R	1
2R	3
3R	0
Average	1.1666667

Slipper Bushing % Exposed Copper	
1L	8
2L	5
3L	4
1R	6
2R	6
3R	3
Average	5.33

Photographs

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Ring Pack 1 Left

Ring Pack 1 Right

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Piston 1 Left Thrust

Piston 1 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Piston 1 Right Thrust

Piston 1 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Liner 1 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Liner 1 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Ring Pack 2 Left

Ring Pack 2 Right

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Piston 2 Left Thrust

Piston 2 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Piston 2 Right Thrust

Piston 2 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Liner 2 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Liner 2 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Ring Pack 3 Left

Ring Pack 3 Right

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Piston 3 Left Thrust

Piston 3 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Piston 3 Right Thrust

Piston 3 Right Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Liner 3 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Liner 3 Right Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	**EOT Date:**	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	**Test Length:**	240

Slipper Bushings 1R, 2R, 3R

Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle - HT

Oil Code:	LO288074	EOT Date:	8/17/13
Test No.:	LO288074-6V53T1-T-240HT	Test Length:	240

Connecting Rod Bearings

Upper 1L, 2L, 3L, 1R, 2R, 3R

Lower 1L, 2L, 3L, 1R, 2R, 3R

APPENDIX C.

Test Report, LO274845 (LO292039) Revised SCPL, DDC 6V53T

High Temperature Evaluation

EVALUATION OF SCPL AT HIGHT TEMPERATURE
LO-274845 (LO-292039)

Project 14734.21

Detroit Diesel Corporation 6V53T

Test Lubricant: LO-274845 (LO-292039)
Test Fuel: JP8
Test Number: LO274845-6V53T1-T-240HT
Start of Test Date: September 11, 2013
End of Test Date: October 31, 2013
Test Duration: 200 Hours
Test Procedure: Tracked Vehicle Engine Cycle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of LO-274845 (LO-292039) at high temperatures when used in the Detroit Diesel Corporation (DDC) 6V53T engine, by the procedures outlined in the Tracked Vehicle Engine Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.21, Single Common Powertrain Lubricants for Combat/Tactical Equipment..

Test Engine

The oil was evaluated in the DDC 6V53T turbo-supercharged diesel engine representative of engines currently fielded in the M113 Armored Personnel Carrier (APC). Prior to testing, the engine was rebuilt using premeasured cylinder kits and rod bearings to provide a known starting condition for post test wear measurements. Engine clearances and specifications were verified, and the engine was assembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for DDC engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperature was controlled through an auxiliary fuel heater loop.

Test Procedure

The procedure outline below is followed in sequential order for each lubricant test in the DDC 6V53T engine.

- Initial Oil Flush:
  -Engine is charged with fresh test oil and a new filter (not weighed).
  -Engine operated at 1200 rpm and 88 lb-ft load until engine and oil temperatures stabilize.
  -Engine shut down and oil charge drained to remove and solvent left from engine rebuild

- Engine Run In:
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is started and run-in following procedures outline below.
  -Immediately after run-in is complete, a no-load governor check is completed (2950-3030rpm). If engine governed speed is out of spec, adjust and retest.

Table 1 - Test Engine Run-In Procedure

Engine Speed [RPM]	Load [lb-ft]	Power (Observed) [bhp]	Duration [min]
1000	None commanded	--	10
2800	None commanded	--	30
1800	88	30	15
2200	310	130	30
2500	420	200	30
2800	422	225	30

- <u>Engine Shake Down:</u>
  -Engine operated for 5hrs at 2800 rpm and 390 lb-ft load
  -After shakedown is complete, engine output is checked at max power and torque load points
  -Completed using run-in oil charge

- <u>Pre Test Engine Powercurve:</u>
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using run-in oil charge. Once complete, engine oil charge is drained and recorded.

- <u>Testing:</u>
  -Engine is charged with fresh test oil and a new filter (weighed and recorded)
  -Engine is operated on test for 240hrs. Test termination can be determined early due to severe piston/liner scuffing, or upon major oil degradation.
  -Oil samples collected daily for used oil analysis
  -Airbox inspections take place at 0, 60, 120, and 180 hours.

- <u>Post Test Engine Powercurve:</u>
  -Full load engine power is mapped over entire speed range in 200 rpm increments
  -Completed using test oil charge. Once complete, engine oil charge is drained and recorded.

Test Cycle

The test cycle followed during oil evaluation was the standard 240 hr Tracked Vehicle Engine Cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at the completion of 240 hrs. Early test termination could be called due to severe oil degradation, or upon experiencing major piston and liner scuffing during the test. The test cycle consists of cyclic modes alternating between idle, max power, and max torque load points. Total daily runtime consisted of 20hrs of operation followed by a 4hr engine off soak period. The cyclic mode consisted of the following modes repeated 4 times daily: 30 minutes at idle speed, 2 hours at max power, 30 minutes of idle speed, 2 hours at max torque. Multiple engine parameters were controlled throughout testing to ensure test consistency, and are specified below in Table 2.

Table 2 - Test Cycle Operating Parameters

Parameter	Max Power	Max Torque	Idle
Speed [rpm]	2800 +/- 25	1600 +/- 25	850 +/- 25
Water Jacket Out [°F]	170 +/- 5	170 +/- 5	170 +/- 5
Inlet Fuel [°F]	100 +/- 5	100 +/- 5	100 +/- 5
Oil Sump [°F]	260 +/- 5	260 +/- 5	NS

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 sourced from a local fuel supplier. (Note: Oil sump specification of 260°F was for the Tracked Vehicle Cycle only. Engine run-in, shakedown, and powercurves were operated at nominally 220°F)

Oil Sampling

Four ounces of engine oil was sampled every 20 hrs for used oil analysis. Engine oil analysis consisted of the following tests outlined in Table 3. All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Table 3 - Used Oil Analysis Procedures

Daily Used Oil Analysis	
ASTM D445	Kinematic Viscosity @ 100°C
ASTM D5185	Wear Metals by ICP
ASTM D4739	Total Base Number
ASTM D664	Total Acid Number

Used oil analysis results can be seen in the engine oil analysis section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred daily after the completion of the 4hr soak prior to restarting testing. All oil additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Engine Operating Conditions Summary

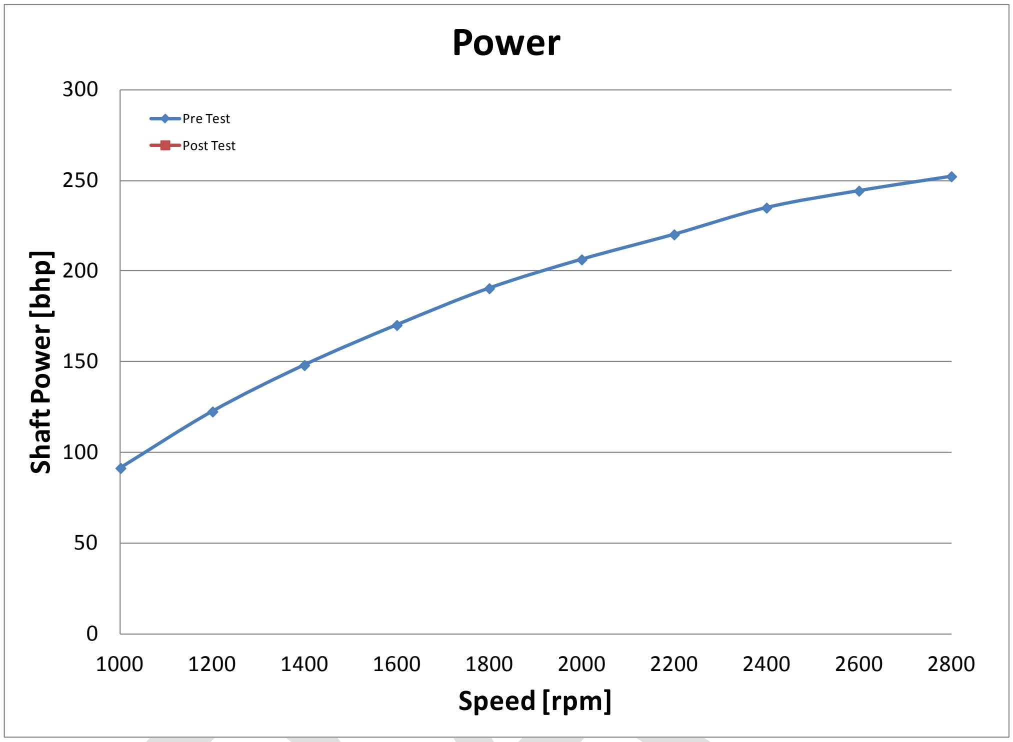
Below is a summary of the engine operating conditions over the test duration. The complete 240hr test schedule was not completed by the lubricant due to excessive liner scuffing.

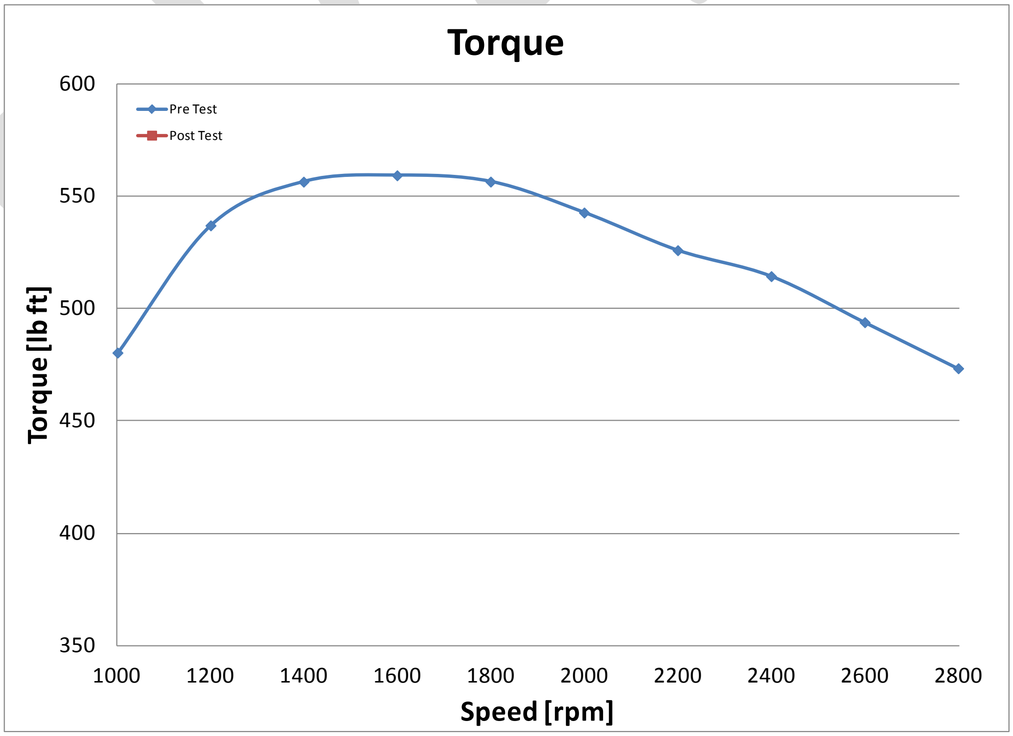
		Peak Power (2800 RPM) 0-160hrs		Peak Torque (1600 RPM) 0-160hrs		Idle Conditions (850 RPM) 0-160hrs	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	2799.98	1.00	1600.01	0.67	875.66	87.75
Torque*	ft*lb	450.15	17.88	529.14	17.51	3.70	12.77
Fuel Flow	lb/hr	89.97	3.01	60.41	1.92	3.57	1.24
Power*	bhp	239.98	9.53	161.20	5.33	0.75	2.93
BSFC*	lb/bhp*hr	0.375	0.005	0.375	0.004	-	-
Engine Blowby	acfm	7.82	1.76	6.86	0.61	5.36	0.98
Temperatures:							
Coolant In	°F	161.10	1.14	158.82	1.06	165.57	5.25
Coolant Out	°F	169.99	0.85	170.00	0.83	168.34	5.66
Oil Galley	°F	238.82	8.57	247.42	4.96	212.68	21.37
Oil Sump	°F	260.25	1.23	259.96	0.68	214.65	21.66
Fuel In	°F	100.08	0.59	100.02	0.55	99.72	1.15
Dry Bulb	°F	88.51	5.84	87.62	6.34	86.19	6.12
Intake Air	°F	84.52	3.22	84.49	2.83	83.29	2.34
Air After Turbo	°F	269.09	8.91	194.00	5.71	92.14	3.50
Air After Supercharger	°F	255.61	27.82	196.24	15.00	151.98	19.16
Cylinder 1R Exhaust	°F	848.92	24.54	620.39	17.30	193.28	37.38
Cylinder 2R Exhaust	°F	885.95	13.32	752.67	8.54	186.04	20.79
Cylinder 3R Exhaust	°F	803.68	34.65	678.65	21.93	178.16	21.87
Cylinder 1L Exhaust	°F	843.24	19.90	690.68	15.02	261.46	43.64
Cylinder 2L Exhaust	°F	933.85	16.13	906.73	14.18	233.34	31.11
Cylinder 3L Exhaust	°F	900.59	26.17	857.07	16.70	236.01	49.92
Exhaust Exit Left	°F	917.04	17.26	879.73	15.08	247.35	45.55
Exhaust Exit Right	°F	818.63	22.12	714.79	17.97	180.43	20.65
Exhaust After Turbo	°F	713.45	17.89	704.82	12.39	231.43	32.78
Pressures:							
Oil Galley	psiG	34.60	0.91	20.03	0.36	12.06	2.54
Crankcase Pressure	inH20	0.28	0.06	0.06	0.02	0.02	0.02
Ambient Pressure	psiA	14.34	0.04	14.13	0.07	14.34	0.04
Pressure After Turbo	psiG	16.97	0.89	9.18	0.49	0.13	0.72
Pressure After Supercharger	psiG	18.53	0.86	8.57	0.44	0.47	0.26
Pressure Exhaust Left	psiG	15.80	0.91	7.75	0.38	0.19	0.18
Pressure Exhaust Right	psiG	15.38	0.75	7.54	0.49	0.17	0.16
Pressure Exhaust After Turbo	psiG	0.71	0.11	0.06	0.06	-0.02	0.00
Fuel Pressure	psiG	64.74	0.66	54.66	1.26	22.37	4.28

* Non-corrected Values

Engine Performance Curves

Note – Post test powercurves not conducted due to engine liner condition at EOT.





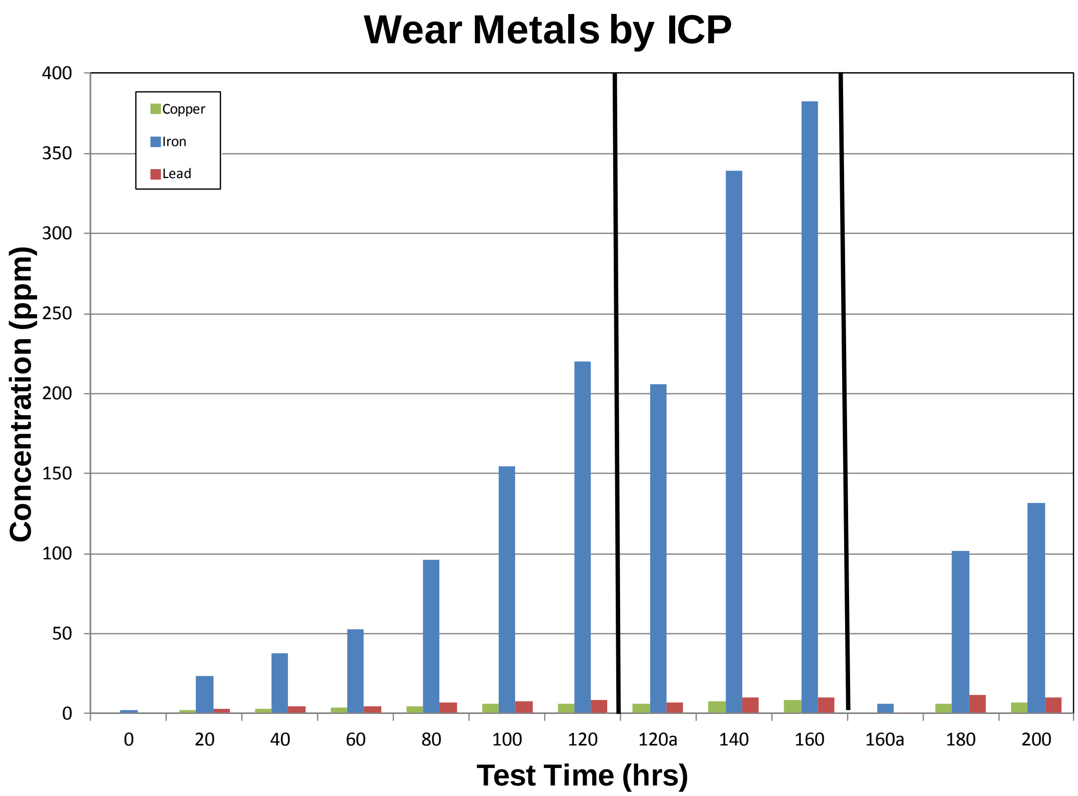
Engine Oil Analysis

Note – Liner 2R changed at 120hrs, but oil charge reused. Oil changed from LO274845 to LO292039 at 160hrs with 1R, 2R, & 3R liner changes.

Property	ASTM Test	Test Hours														
		0	20	40	60	80	100	120	120a	140	160	160a	180	200	220	240
Viscosity @ 100°C (cSt)	D445	8.6	8.7	8.9	9.1	9.2	9.3	9.4	9.2	9.8	10.0	8.5	8.6	8.9		
Total Base Number (mg KOH/g)	D4739	9.9	8.8	8.4	8.0	7.7	7.2	7.7	7.7	7.3	7.0	10.1	8.8	8.2		
Total Acid Number (mg KOH/g)	D664	1.9	1.9	2.0	2.1	2.2	2.2	2.3	2.1	2.4	2.4	2.0	2.2	2.2		
Wear Metals (ppm)	D5185															
Al		<1	1	1	2	2	2	2	3	3	4	1	2	2		
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
B		18	16	16	17	15	14	14	15	13	14	17	16	16		
Ca		924	994	1024	1019	1052	1051	1033	1057	1092	1130	912	957	976		
Cr		<1	<1	2	2	3	4	6	5	8	9	<1	2	3		
Cu		<1	2	3	4	5	6	6	6	8	9	<1	6	7		
Fe		2	24	38	53	96	155	220	206	339	383	6	102	132		
Pb		<1	3	5	5	7	8	9	7	10	10	1	12	10		
Mg		1375	1441	1462	1494	1519	1537	1554	1579	1638	1667	1369	1452	1462		
Mn		<1	<1	<1	<1	1	2	2	2	4	4	<1	1	2		
Mo		66	71	73	76	79	84	88	87	97	100	66	76	79		
Ni		<1	<1	<1	<1	1	2	2	2	4	4	<1	1	<1		
P		1171	1167	1153	1136	1129	1136	1140	1184	1183	1181	1132	1127	1091		
Si		6	19	24	37	38	39	39	35	47	47	6	30	36		
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
Na		<5	7	10	9	9	11	10	14	14	13	6	8	13		
Sn		<1	16	21	22	23	27	30	26	44	44	<1	28	29		
Zn		1279	1310	1305	1319	1333	1359	1358	1399	1431	1451	1256	1283	1309		
K		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5		
Sr		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1		

Engine Oil Analysis Trends

Note – Liner 2R changed at 120hrs, but oil charge reused. Oil changed from LO274845 to LO292039 at 160hrs with 1R, 2R, & 3R liner changes.



Engine Measurements

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8757	3.8764		0.0007
	25mm Above Port	3.8763	3.8766	3.8764	0.0003
	25mm Below Port	3.8763	3.8765		0.0002
	13mm From Bottom	3.8764	3.8768		0.0004
	Taper	0.0007	0.0004		
2L	13mm From Top	3.8766	3.8763		0.0003
	25mm Above Port	3.8762	3.8757	3.8761	0.0005
	25mm Below Port	3.8760	3.8757		0.0003
	13mm From Bottom	3.8767	3.8755		0.0012
	Taper	0.0007	0.0008		
3L	13mm From Top	3.8770	3.8761		0.0009
	25mm Above Port	3.8765	3.8760	3.8764	0.0005
	25mm Below Port	3.8762	3.8762		0.0000
	13mm From Bottom	3.8762	3.8768		0.0006
	Taper	0.0008	0.0008		
1R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
2R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
3R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA	Out of Round
1L	13mm From Top	3.8767	3.8763		0.0004
	25mm Above Port	3.8758	3.8760	3.8760	0.0002
	25mm Below Port	3.8759	3.8758		0.0001
	13mm From Bottom	3.8750	3.8762		0.0012
	Taper	0.0017	0.0005		
2L	13mm From Top	3.8768	3.8771		0.0003
	25mm Above Port	3.8764	3.8766	3.8766	0.0002
	25mm Below Port	3.8762	3.8768		0.0006
	13mm From Bottom	3.8768	3.8761		0.0007
	Taper	0.0006	0.0010		
3L	13mm From Top	3.8776	3.8799		0.0023
	25mm Above Port	3.8769	3.8784	3.8775	0.0015
	25mm Below Port	3.8770	3.8770		0.0000
	13mm From Bottom	3.8766	3.8768		0.0002
	Taper	0.0010	0.0031		
1R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
2R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
3R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Thrust/Anti-Thrust	Front/Back	Avg Bore DIA Change	Out of Round
1L	13mm From Top	0.0010	0.0001		0.0003
	25mm Above Port	0.0005	0.0006	0.0007	0.0001
	25mm Below Port	0.0004	0.0007		0.0001
	13mm From Bottom	0.0014	0.0006		0.0008
	Taper	0.0010	0.0006		
2L	13mm From Top	0.0002	0.0008		0.0000
	25mm Above Port	0.0002	0.0009	0.0005	0.0003
	25mm Below Port	0.0002	0.0011		0.0003
	13mm From Bottom	0.0001	0.0006		0.0005
	Taper	0.0001	0.0005		
3L	13mm From Top	0.0006	0.0038		0.0014
	25mm Above Port	0.0004	0.0024	0.0012	0.0010
	25mm Below Port	0.0008	0.0008		0.0000
	13mm From Bottom	0.0004	0.0000		0.0004
	Taper	0.0004	0.0038		
1R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
2R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
3R	13mm From Top				0.0000
	25mm Above Port			#DIV/0!	0.0000
	25mm Below Port				0.0000
	13mm From Bottom				0.0000
	Taper				
Avgerage All Cylinders	13mm From Top	0.0006	0.0016		
	25mm Above Port	0.0004	0.0013		
	25mm Below Port	0.0005	0.0009		
	13mm From Bottom	0.0006	0.0004		

Pre-Test Liner Surface Finish, µm

Pre Test Liner Surface Finish, µm					
1L	2L	3L	1R	2R	3R
1.06	1.02	1.11	1.2	1.14	1.24

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1L	3.8764	3.8712	0.0052
	2L	3.8761	3.8714	0.0047
	3L	3.8764	3.8713	0.0051
	1R	#DIV/0!	3.8709	#DIV/0!
	2R	#DIV/0!	3.8718	#DIV/0!
	3R	#DIV/0!	3.8717	#DIV/0!
Post - Test	1L	3.8760	3.8695	0.0065
	2L	3.8766	3.8694	0.0072
	3L	3.8775	3.8693	0.0082
	1R	#DIV/0!	3.8691	#DIV/0!
	2R	#DIV/0!	3.8693	#DIV/0!
	3R	#DIV/0!	3.8694	#DIV/0!

Connecting Rod Bearing Mass Change, grams

Rod Bearing	Shell	Before	After	Change
1L	Top	73.2583	73.2302	0.0281
	Bottom	68.2943	68.2889	0.0054
2L	Top	73.3244	73.3023	0.0221
	Bottom	69.1636	69.1615	0.0021
3L	Top	73.3533	73.3362	0.0171
	Bottom	68.6608	68.6584	0.0024
1R	Top			0.0000
	Bottom			0.0000
2R	Top			0.0000
	Bottom			0.0000
3R	Top			0.0000
	Bottom			0.0000

Maximum	0.0281
Average	0.0064

Slipper Bushing Mass Change, grams

Slipper Bushing	Before	After	Change
1L	55.8944	55.7998	0.0946
2L	55.9607	55.8983	0.0624
3L	55.9911	55.7765	0.2146
1R			0.0000
2R			0.0000
3R			0.0000

Maximum	0.2146
Average	0.0619

Pre-Test Slipper Bushing Tin Plate Thickness, inches

Slipper Bushing Tin Plate Thickness					
1L	2L	3L	1R	2R	3R
0.02160	0.02035	0.02070			

Top, Second, and Third Ring Radial Measurements, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.15590	0.15535	0.00055
	2	0.15720	0.15710	0.00010
	3	0.15690	0.15650	0.00040
	4	0.15625	0.15585	0.00040
	5	0.15490	0.15390	0.00100
2L	1	0.15260	0.15180	0.00080
	2	0.15660	0.15585	0.00075
	3	0.15695	0.15665	0.00030
	4	0.15710	0.15595	0.00115
	5	0.15455	0.15330	0.00125
3L	1	0.15615	0.15330	0.00285
	2	0.15680	0.15515	0.00165
	3	0.15665	0.15635	0.00030
	4	0.15700	0.15615	0.00085
	5	0.15495	0.15355	0.00140
1R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
2R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
3R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00285
Average	0.00055

Second Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14840	0.14780	0.00060
	2	0.14740	0.14680	0.00060
	3	0.14665	0.14635	0.00030
	4	0.14870	0.14825	0.00045
	5	0.14815	0.14765	0.00050
2L	1	0.14790	0.14680	0.00110
	2	0.14770	0.14665	0.00105
	3	0.14785	0.14735	0.00050
	4	0.14730	0.14540	0.00190
	5	0.14805	0.14640	0.00165
3L	1	0.14815	0.14385	0.00430
	2	0.14770	0.14675	0.00095
	3	0.14770	0.14605	0.00165
	4	0.14770	0.14590	0.00180
	5	0.14775	0.14540	0.00235
1R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
2R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
3R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00430
Average	0.00079

Third Ring				
Cylinder	Position	Before	After	Delta
1L	1	0.14680	0.14640	0.00040
	2	0.14825	0.14785	0.00040
	3	0.14780	0.14745	0.00035
	4	0.14705	0.14675	0.00030
	5	0.14620	0.14590	0.00030
2L	1	0.14770	0.14690	0.00080
	2	0.14865	0.14815	0.00050
	3	0.14865	0.14810	0.00055
	4	0.14695	0.14630	0.00065
	5	0.14760	0.14650	0.00110
3L	1	0.14755	0.14645	0.00110
	2	0.14840	0.14735	0.00105
	3	0.14825	0.14750	0.00075
	4	0.14785	0.14665	0.00120
	5	0.14770	0.14640	0.00130
1R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
2R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
3R	1			0.00000
	2			0.00000
	3			0.00000
	4			0.00000
	5			0.00000
*Note - Measurements with a negitive delta value, shown in italics, are considered pre-test measurements error				

Maximum	0.00130
Average	0.00043

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Increase
1L	1	0.030	0.031	0.001
	2	0.030	0.033	0.003
	3	0.030	0.033	0.003
	4	0.018	0.022	0.004
	5a	0.018	0.021	0.003
	5b	0.019	0.021	0.002
2L	1	0.036	0.039	0.003
	2	0.030	0.037	0.007
	3	0.029	0.033	0.004
	4	0.016	0.021	0.005
	5a	0.015	0.017	0.002
	5b	0.016	0.019	0.003
3L	1	0.030	0.039	0.009
	2	0.031	0.042	0.011
	3	0.030	0.037	0.007
	4	0.015	0.028	0.013
	5a	0.016	0.020	0.004
	5b	0.016	0.020	0.004
1R	1			0.000
	2			0.000
	3			0.000
	4			0.000
	5a			0.000
	5b			0.000
2R	1			0.000
	2			0.000
	3			0.000
	4			0.000
	5a			0.000
	5b			0.000
3R	1			0.000
	2			0.000
	3			0.000
	4			0.000
	5a			0.000
	5b			0.000

Ring No. 1 max increase	0.009
Ring No. 2 max increase	0.011
Ring No. 3 max increase	0.007
Ring No. 4 max increase	0.013
Ring No. 5a max increase	0.004
Ring No. 5b max increase	0.004

Ring No. 1 avg increase	0.003
Ring No. 2 avg increase	0.004
Ring No. 3 avg increase	0.003
Ring No. 4 avg increase	0.004
Ring No. 5a avg increase	0.002
Ring No. 5b avg increase	0.002

Piston Ring Mass Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1L	1	22.9395	22.9353	0.0042
	2	20.2334	20.1810	0.0524
	3	20.1933	20.1634	0.0299
	4	27.6769	27.6619	0.0150
	5	24.5597	24.5403	0.0194
2L	1	22.9998	22.9923	0.0075
	2	20.2156	20.0700	0.1456
	3	20.2635	20.1877	0.0758
	4	27.8059	27.7920	0.0139
	5	24.0052	23.9765	0.0287
3L	1	22.9597	22.9331	0.0266
	2	20.2521	19.9914	0.2607
	3	20.2883	20.1909	0.0974
	4	27.7983	27.7838	0.0145
	5	23.8496	23.8138	0.0358
1R	1			0.0000
	2			0.0000
	3			0.0000
	4			0.0000
	5			0.0000
2R	1			0.0000
	2			0.0000
	3			0.0000
	4			0.0000
	5			0.0000
3R	1			0.0000
	2			0.0000
	3			0.0000
	4			0.0000
	5			0.0000

Ring No. 1 max decrease	0.0266
Ring No. 2 max decrease	0.2607
Ring No. 3 max decrease	0.0974
Ring No. 4 max decrease	0.0150
Ring No. 5 max decrease	0.0358

Ring No. 1 avg decrease	0.0077
Ring No. 2 avg decrease	0.0917
Ring No. 3 avg decrease	0.0406
Ring No. 4 avg decrease	0.0087
Ring No. 5 avg decrease	0.0168

Oil Control & Expander Ring Tension, pounds

	Oil Control & Expander Ring Tension					
	1L	2L	3L	1R	2R	3R
Top Oil Ring	10.7	12.1	11.2			
Second Oil Ring	11.3	11.6	11.8			

NOTE – To be used as reference only.
Measurements taken with uncalibrated legacy equipment.

<u>Post Test Engine Ratings</u>

Piston Ratings, Demerits

Ratings	Cylinder Number						
	1L	2L	3L	1R	2R	3R	**Avg**
Ring Sticking (F=Free, CS=Cold Stuck, HS=Hot Stuck, CP=Collapsed Ring, No. Denotes % Of Ring Circumference)							
Top	F (25%CP)	F (25%CP)	F (60%CP)				--
Second	F	F	F				--
Third	F	F	F				--
Oil Control Rings	F	F	F				--
2nd Ring Carbon							
Heavy Carbon							--
Light Carbon							--
Piston Carbon, Demerits							
No.1 Groove	41.00	30.00	37.75				36.25
No.2 Groove	30.25	25.00	33.25				29.50
No.3 Groove	24.50	25.75	25.00				25.08
No.1 Land	36.25	28.00	37.00				33.75
No.2 Land	60.25	46.00	40.00				48.75
No.3 Land	15.75	22.00	33.00				23.58
No.4 Land	10.00	10.50	15.25				11.92
Piston Lacquer, Demerits							
No.1 Groove	0.00	0.00	0.00				0.00
No.2 Groove	0.00	0.00	0.00				0.00
No.3 Groove	0.00	0.00	0.00				0.00
No.1 Land	0.00	0.00	0.00				0.00
No.2 Land	0.00	0.00	0.00				0.00
No.3 Land	1.33	0.73	0.92				0.99
No.4 Land	1.75	2.23	1.29				1.76
Total, Demerits	221.08	190.21	223.46	0.00	0.00	0.00	105.79
Miscellanous							
Top Groove Fill, %	37	24	19				26.67
Intermediate Groove Fill, %	43	27	47				39.00
Top Land Heavy Carbon, %	15	4	16				11.67
Top Land Flaked Carbon, %	0	0	0				0.00

Ring Face Distress, Demerits

Cylinder No.	Ring No.	Extreme Distress (1.00) % Area	Heavy Distress (0.75) % Area	Medium Distress (0.50) % Area	Light Distress (0.25) % Area	No Distress (0.00) % Area	Total Demerits
1L	1				17	83	0.043
	2				22	78	0.055
	3				25	75	0.063
2L	1				76	24	0.190
	2				92	8	0.230
	3				100	0	0.250
3L	1				100	0	0.250
	2				100	0	0.250
	3				96	4	0.240
1R	1						
	2						
	3						
2R	1						
	2						
	3						
3R	1						
	2						
	3						

Piston Ring Face Distress	Fire Ring	2nd Ring	3rd Ring
Average Demerits	0.1608	0.1783	0.1842

EOT Cylinder Liner Ratings, % Area

	Cylinder Liner Ratings					
	% Scuffing		Total % Area Scuffed	% Polish		Total % Area Polished
	T	AT		T	AT	
1L	1	4	5	0	5	5
2L	15	22	37	5	4	9
3L	40	50	90	0	0	0
1R			0			0
2R			0			0
3R			0			0
Percent of total ring travel area						

Piston Skirt Ratings

	Piston Skirt Ratings	
	Thrust	Anti-Thrust
1L	2% Scuffed & Light Scratches	Very Light Scratches
2L	20% Scuffed & Light Scratches	25% Scuffed & Light Scratches
3L	35% Scuffed & Light Scratches	Very Light to Light Scratches
1R		
2R		
3R		

EOT Intake Port Plugging & Slipper Bushing Exposed Copper, %

Intake Port Plugging	
1L	0
2L	0
3L	0
1R	
2R	
3R	
Average	0

Slipper Bushing % Exposed Copper	
1L	0
2L	0
3L	1
1R	
2R	
3R	
Average	0.33

Photographs

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	EOT Date:	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	Test Length:	200

Ring Pack 1 Left

Ring Pack 1 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Piston 1 Left Thrust

Piston 1 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	EOT Date:	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	Test Length:	200

Liner 1 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Ring Pack 2 Left

Ring Pack 2 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Piston 2 Left Thrust

Piston 2 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	EOT Date:	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	Test Length:	200

Liner 2 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Ring Pack 3 Left

Ring Pack 3 Right

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Piston 3 Left Thrust

Piston 3 Left Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Liner 3 Left Thrust and Anti-thrust

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Slipper Bushings 1R, 2R, 3R

Slipper Bushings 1L, 2L, 3L

DDC 6V53T - Tracked Vehicle Cycle

Oil Code:	LO274845/LO300491	**EOT Date:**	11/1/13
Test No.:	LO274845-6V53T1-T-240HT	**Test Length:**	200

Connecting Rod Bearings

Upper 1L, 2L, 3L, 1R, 2R, 3R **Lower 1L, 2L, 3L, 1R, 2R, 3R**

APPENDIX D.
Mack T-12 Test Reports

Mack T-12
EGR Engine Oil Test

Version 20100308

Title / Validity Declaration Page

Form 1

Conducted for

SOUTHWEST RESEARCH INSTITUTE

V	V = Valid; The Reference Oil/Non Reference Oil was Evaluated in Accordance with the Test Procedure.
	I = Invalid; The Reference Oil/Non-Reference Oil was not Evaluated in Accordance with the Test Procedure.
	N = Results cannot be Interpreted as Representative of Oil Performance (Non-Reference Oil) and shall not be used in Determining an Average Test Result using Multiple Test Criteria

NR	NR = Non Reference Oil Test
	RO = Reference Oil Test

Stand: 83	**Stand Run No.:** 108	**Engine No.:** 2M7188	**Engine Hours:** 1208
End of Test Date: 20141010		**End of Test Time:** 06:12	
Oil Code / CMIR:[A] LO292039			
Formulation / Stand Code:[B]			
Altcode1:[C]	**Altcode2:**[C]	**Altcode3:**[C]	

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D7422 and the appropriate amendments through the information letter system. The remarks included in this report the anomalies associated with this test.

[A] *CMIR or Non-Reference Oil Code*

[B] *ACC-Registered Tests Only*

[C] *When Provided or Required by Client*

Submitted by: **Southwest Research Institute (R)**
Testing Laboratory

Signature

Robert W. Warden
Typed Name

Research Engineer
Title

Mack T-12
EGR Engine Oil Test
Table of Contents
Form 2

Laboratory:	SR	EOT Date:	20141010	EOT Time:	06:12
Test Number:	83-108-2M7188-1208	Oil Code:	LO292039		
Formulation / Stand Code:					

[A] *ACC-Registered Tests Only*

Mack T-12
EGR Engine Oil Test
Summary of Test Method
Form 3

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	06:12
Test Number:	83-108-2M7188-1208	**Oil Code:**	LO292039		
Formulation / Stand Code:					

The Mack T-12 EGR Engine Oil Test is a fuel engine-dynamometer test which evaluates the ability of a lubricant to minimize piston ring wear, cylinder liner wear, and lead corrosion, oil consumption, and oxidation. This test is a two-phase, steady state test (constant speed and load), run with heavy EGR. The first phase is 100 hours and is run with retarded fuel injection timing to produce elevated soot levels in the oil. The second phase is 200 hours and is run under heavy load conditions to induce piston ring and cylinder liner wear.

The test engine is a Mack E-TECH V-MAC III diesel engine with EGR. It is an in-line six cylinder, four-stroke, turbocharged engine. It has electronically controlled fuel injection with six individual electronic unit pumps. A one hour break-in is conducted prior to each test since a new engine build is used for each test.

Mack T-12 Test Conditions

Parameter	Phase I	Phase II
Time, h	100	200
Injection Timing, °BTDC	Variable	21
Speed, r/min	1800	1200
Fuel Flow, kg/h	59.2	63.5
Intake CO_2, %	3.09	1.42
Exhaust CO_2, %	9.25	9.78-10.08 typical
Inlet Manifold Temp., °C	90	80
Coolant Out Temp., °C	66	108
Fuel In Temp., °C	40	40
Oil Gallery Temp., °C	88	116
Intake Air Temp., °C	25	25
Intake Air Restriction, kPa	3.5 - 4.0	3.5 - 4.0
Inlet Manifold Pressure, kPa	265 Nominal	302-312
Exhaust Back Pressure, kPa	2.7 - 3.5	2.7 - 3.5
Crankcase Pressure, kPa	0.25 - 0.75	0.25 - 0.75
Power, kW	Record	Record
Torque, Nm	Record	Record
Pre-Turbine Exhaust Temp., °C	Record	Record
Tailpipe Exhaust Temp., °C	Record	Record
Oil Sump Temp., °C	Record	Record
EGR Pre-Venturi Temp., °C	Record	Record
Inlet Air Dew Point, °C	Record	Record
Inlet Air Humidity, kg/kg	Record	Record
Main Gallery Oil Pressure, kPa	Record	Record
Oil Filter Delta P, kPa	Not to exceed 138	Not to exceed 138

Mack T-12
EGR Engine Oil Test
Test Results Summary
Form 4

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	06:12
Test Number:	83-108-2M7188-1208	**Oil Code:**	LO292039		
Formulation / Stand Code:					

Test Results					
Date Test Started: 20140926	Start Time: 22:58		Test Length: 300		
TMC Oil Code: [A]	Laboratory Oil Code: LO-292039		SAE Viscosity: N/A		
Average TGA Soot % at 100 h	4.3				
Centrifugal Oil Filter Mass Gain, g	399.2				
Oil Filter Delta P, kPa (138 maximum)	12				
EOT TBN	3.9				
	Delta Pb @ EOT (ppm)	**Avg. Liner Wear (µm)**	**Avg. Top Ring Weight Loss (mg)**	**Oil Consumption (g/h)**	**Delta Pb 250-300h (ppm)**
Original Result	40	29.7	63	101.1	17
Transformed Result [B]	3.6889	29.7000	63.0000	4.6161	2.8332
Correction Factor [B]	0.8130	0.8180	0.7190	0.9130	0.7100
Corrected Transformed Result [B]	2.9991	24.2946	45.2970	4.2145	2.0116
Severity Adjustment [B]	0.0000	1.1294	0.0000	-0.0496	0.0000
Final Transformed Result [B]	2.9991	25.4240	45.2970	4.1649	2.0116
Final Original Unit Result	20	25.4	45	64.4	7
Mack Merits [C]	266.7	-87.5	342.9	156.0	260.0
Total Mack Merits: [C]	938.1				

Last Stand Reference Results					
Test Number:	83-99A-2M6341-300				
Oil Code:	CMIR-97766 SR-101				
Test Length: 300		TMC Oil Code: [A] 821-3			
EOT Date: 20131216		EOT Time: 04:58			
Number of Tests Since Stand Calibration: [D]	5				
Stand Calibration Expiration Date:					
Average TGA Soot % at 100 h:	4.4				
	Delta Pb @ EOT (ppm)	**Avg. Liner Wear (µm)**	**Avg. Top Ring Weight Loss (mg)**	**Oil Consumption (g/h)**	**Delta Pb 250-300h (ppm)**
Final Original Unit Result	18	10.1	48	62.9	8

A Reference Tests Only
B Transformed Units apply to Delta Pb, @ EOT, Oil Consumption, and Delta 250-300 h only.
C Non-Reference Tests Only
D Operationally valid tests only, including current test.

Mack T-12
EGR Engine Oil Test
Operational Summary
Form 5

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

	Parameter	Units	QI Threshold	EOT QI[A]	Target		Average		Samples[B]	BQD[C]	Over/Under Range[D]
Controlled Parameters	Speed	r/min	0.000	1.000	1800	1200	1800	1200	3000	0	0
	Fuel Flow	kg/h	0.000	0.998	59.2	63.5	59.19	63.50	3000	0	0
	Inlet Manifold Temp.	°C	0.000	0.368	90	80	91	80	3000	0	0
	Coolant Out Temp.	°C	0.000	0.884	66	108	66	108	3000	0	0
	Fuel In Temp.	°C	0.000	0.985	40		40		3000	0	0
	Oil Gallery Temp.	°C	0.000	0.309	88	116	88	116	3000	0	0
	Intake Air Temp.	°C	0.000	0.891	25		25		3000	0	0
	Inlet Air Restriction	kPa			3.5 - 4.0		3.73		3000	0	0
	Inlet Man. Pressure	kPa			265 Nominal	307 ± 5	263	308	3000	0	0
	Exh. Back Pressure	kPa			2.7 - 3.5		3.1		3000	0	0
	Crankcase Pressure	kPa			0.25 - 0.75		0.74		3000	0	0
	Intake CO_2	%			3.09 ± .05	1.42 ± .05	3.07	1.40			
	Exhaust CO_2	%			9.25 ± .15	9.93 ± .15	9.27	10.04			

	Parameter	Units	Typical Values[E]		Average	
Non-controlled Parameters	Torque	Nm	1232-1397	2434-2543	1360	2495
	Brake Specific Fuel Cons.	g/kW-h	212-263	179-228	230.8	202.5
	Pre-Turbine Temp. (L)	°C	482-605	504-759	541	641
	Pre-Turbine Temp. (R)	°C	503-567	491-758	532	631
	Tailpipe Temp.	°C	303-354	280-433	311	399
	Oil Sump Temp.	°C	92-105	73-190	96	128
	EGR Pre-Venturi Temp.	°C	138-201	107-126	155	121
	Blowby	L/min	41-176	71-264	0.0	0.0
	Inlet Air Dew Point	°C	6-22	6-22	22	22
	EGR Pre-Venturi Pressure	kPa	226-331	235-336	283	283
	Main Gallery Oil Pressure	kPa	394-502	165-269	332	163

A QI values above the threshold are acceptable by the Mack Surveillance Panel. QI values below the threshold may not be considered acceptable based on an engineering review. Refer to Annex A5.
B Total number of data points taken. Minimum acceptable value is 3000.
C Number of Bad Quality Data points not used in the calculation of the statistical measures.
D Number of points clipped by over/under range limits.
E Typical values determined from reference oil test database.

Mack T-12
EGR Engine Oil Test
Rod Bearing Weight Loss
Form 6

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	06:12
Test Number:	83-108-2M7188-1208	**Oil Code:**	LO292039		
Formulation / Stand Code:					

Cylinder #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Upper	98.5387	98.3111	227.6
2	Upper	98.4897	98.2718	217.9
3	Upper	98.7648	98.4125	352.3
4	Upper	98.5149	98.3045	210.4
5	Upper	98.5175	98.2977	219.8
6	Upper	98.6252	98.3200	305.2

Summary	As Measured	Outlier Screened
Upper Bearing Average Weight Loss, mg	255.5	255.5
Upper Bearing Weight Loss Std. Dev., mg	58.9	58.9
Upper Bearing Minimum Weight Loss, mg	210.4	210.4
Upper Bearing Maximum Weight Loss, mg	352.3	352.3
Outlier Upper Rod Bearing [A]	N	

[A] *Cylinder number*

Cylinder #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Lower	98.0867	98.0829	3.8
2	Lower	97.9984	97.9932	5.2
3	Lower	97.9679	97.9631	4.8
4	Lower	97.9015	97.8997	1.8
5	Lower	97.7933	97.7890	4.3
6	Lower	97.6650	97.6641	0.9
Lower Bearing Average Weight Loss, mg				3.5
Lower Bearing Weight Loss Std. Dev., mg				1.7
Lower Bearing Minimum Weight Loss, mg				0.9
Lower Bearing Maximum Weight Loss, mg				5.2

Conrod Bearing Batch ID	180919-X

Mack T-12
EGR Engine Oil Test
Ring Weight Loss
Form 7

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

Cylinder No.	Top Ring SOT Weight, g	Top Ring EOT Weight, g	Weight Loss, mg
1	31.3774	31.2829	94.5
2	31.3696	31.3163	53.3
3	31.2862	31.2404	45.8
4	31.3666	31.3294	37.2
5	31.4059	31.3260	79.9
6	31.2560	31.1869	69.1

Summary	As Measured [A]	Outlier Screened
Top Ring Average Weight Loss, mg	63	63
Top Ring Weight Loss Std. Dev., mg	21.8	21.8
Top Ring Minimum Weight Loss, mg	37.2	37.2
Top Ring Maximum Weight Loss, mg	94.5	94.5
Outlier Ring [B]	N	

[A] Results calculated without rings with plasma flaking.

[B] Ring number wear results are not currently outlier screened.

Cylinder No.	2nd Ring SOT Weight, g	2nd Ring EOT Weight, g	Weight Loss, mg
1	27.2100	27.1724	37.6
2	27.2182	27.1949	23.3
3	27.2668	27.2410	25.8
4	27.2009	27.1767	24.2
5	27.2668	27.2395	27.3
6	27.0766	27.0431	33.5
		2nd Ring Average Weight Loss, mg	28.6
		2nd Ring Weight Loss Std. Dev.,mg	5.7
		2nd Ring Min. Weight Loss, mg	23.3
		2nd Ring Max. Weight Loss, mg	37.6

Cylinder No.	Oil Ring SOT Weight, g	Oil Ring EOT Weight, g	Weight Loss, mg
1	36.9154	36.8868	28.6
2	37.2910	37.2648	26.2
3	37.1347	37.1074	27.3
4	36.2557	36.2271	28.6
5	36.3249	36.2950	29.9
6	37.1177	37.0767	41.0
		Oil Ring Average Weight Loss, mg	30.3
		Oil Ring Weight Loss Std. Dev.,mg	5.4
		Oil Ring Min. Weight Loss, mg	26.2
		Oil Ring Max. Weight Loss, mg	41.0

Mack T-12
EGR Engine Oil Test
Oil Analysis Summary
Form 8

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

Hours	Soot Wt. % TGA	Viscosity at 100°C cSt	Viscosity Increase cSt	TBN	TAN	IR Oxidation		Metals Elements (ppm)								
						Integrated	Peak Height	Fe	Pb	Cu	Cr	Al	Si	Sn	Na	Ni
000	0.2	8.57	[redacted]	9.8	2.4	0.0	0.0	1	1	<1	<1	1	4	<1	14	<1
025	1.1	8.75	0.18	9.1	1.8	-17.4	1.5	17	2	7	<1	2	12	<1	9	<1
050	2.1	9.12	0.55	8.3	2.0	-61.1	2.5	27	3	10	1	2	14	<1	12	<1
075	3.2	9.67	1.10	7.8	2.3	-53.8	4.4	45	2	12	2	3	17	<1	13	2
100	4.3	10.07	1.50	7.2	2.3	-81.9	5.8	59	3	14	3	4	19	<1	10	2
100 (2nd)	4.3	[redacted]														
100 Avg.	4.3															
125	4.6	10.16	1.59	5.4	3.2	48.4	12.6	123	9	27	4	4	23	3	15	2
150	5.1	10.66	2.09	5.1	3.4	144.7	16.4	167	9	40	5	6	27	4	17	2
175	5.2	11.08	2.51	4.0	3.6	301.0	19.8	190	10	38	6	6	28	5	21	2
200	5.7	11.82	3.25	3.9	3.8	479.3	24.2	230	14	44	7	6	31	5	25	3
225	5.6	12.28	3.71	3.6	3.6	591.6	26.4	254	15	44	7	7	32	5	24	3
250	6.3	13.27	4.70	3.9	3.9	847.6	32.2	284	24	46	7	7	37	6	26	3
275	6.4	13.76	5.19	4.0	4.4	932.5	34.2	310	27	49	8	9	38	7	26	4
300	7.1	15.08	6.51	3.9	5.0	1123.6	38.8	372	41	54	9	10	43	7	28	4

Summary	As Measured	Outlier Bearing
Delta Pb @ EOT, ppm	40	40
Delta Pb 250-300 h, ppm	17	[redacted]
MRV Yield Stress, Pa	0	

MRV @ 100h, cP	1500
MRV @ 100h with Severity Adjustment, cP	2768

Mack T-12
EGR Engine Oil Test
Liner Surface Roughness & Bore Diameter
Form 9

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 06:12	
Test Number: 83-108-2M7188-1208	**Oil Code:** LO292039		
Formulation / Stand Code:			

Liner No.	Location	Ra (µm)	Bore Diameter (mm)		Ra (µm)	Dia. (mm)
1	Top Ring Travel @ 0°	16.60	123.848	Avg	17.15	123.839
	Top Ring Travel @ 90°	16.90	123.830	Std Dev	0.84	
	Top Ring Travel @ 180°	16.70		Min	16.60	
	Top Ring Travel @ 270°	18.40		Max	18.40	
2	Top Ring Travel @ 0°	16.40	123.825	Avg	16.25	123.828
	Top Ring Travel @ 90°	16.90	123.830	Std Dev	0.79	
	Top Ring Travel @ 180°	16.60		Min	15.10	
	Top Ring Travel @ 270°	15.10		Max	16.90	
3	Top Ring Travel @ 0°	18.30	123.840	Avg	17.50	123.835
	Top Ring Travel @ 90°	16.50	123.830	Std Dev	0.75	
	Top Ring Travel @ 180°	17.70		Min	16.50	
	Top Ring Travel @ 270°	17.50		Max	18.30	
4	Top Ring Travel @ 0°	17.70	123.825	Avg	17.60	123.825
	Top Ring Travel @ 90°	17.60	123.825	Std Dev	0.45	
	Top Ring Travel @ 180°	17.00		Min	17.00	
	Top Ring Travel @ 270°	18.10		Max	18.10	
5	Top Ring Travel @ 0°	17.80	123.822	Avg	17.52	123.821
	Top Ring Travel @ 90°	16.50	123.820	Std Dev	0.89	
	Top Ring Travel @ 180°	17.20		Min	16.50	
	Top Ring Travel @ 270°	18.60		Max	18.60	
6	Top Ring Travel @ 0°	17.00	123.843	Avg	17.48	123.832
	Top Ring Travel @ 90°	16.30	123.822	Std Dev	1.08	
	Top Ring Travel @ 180°	17.80		Min	16.30	
	Top Ring Travel @ 270°	18.80		Max	18.80	

	Ra (µm)	Bore Diameter (mm)
Average Surface Roughness & Bore Diameter	17.25	123.830
Standard Deviation Surface Roughness & Bore Diameter	0.51	0.007
Minimum Surface Roughness & Bore Diameter	16.25	123.821
Maximum Surface Roughness & Bore Diameter	17.60	123.839

Mack T-12
EGR Engine Oil Test
Liner Wear Summary
Form 10

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

Position	Wear Step (µm)					
	Cylinder Number					
	1	2	3	4	5	6
1:00	64.8	36.5	40.3	48.5	29.2	48.6
2:00	33.0	28.2	41.6	44.6	26.0	46.3
3:00 (Thrust)	34.2	22.8	51.0	54.4	46.9	65.8
4:00	13.1	17.7	20.0	25.8	44.9	52.3
5:00	23.5	39.1	28.9	35.7	35.3	52.5
6:00 (Rear)	10.5	19.0	15.6	10.5	19.3	49.8
7:00	17.3	23.1	17.7	8.1	17.2	29.3
8:00	24.3	38.2	34.9	21.4	37.5	29.2
9:00 (Anti-Thrust)	45.0	47.8	48.6	36.0	34.5	43.8
10:00	39.3	35.4	42.2	30.8	30.1	42.5
11:00	12.8	19.8	23.4	17.6	19.4	42.2
12:00 (Front)	36.6	15.4	21.4	24.6	17.0	43.3
Average	29.5	28.6	32.1	29.8	29.8	45.5

Summary	As Measured	Outlier Screened
Average, µm	32.6	29.7
Std. Dev., µm	6.4	1.3
Minimum, µm	28.6	28.6
Maximum, µm	45.5	32.1
Outlier Liners [A]	6	

[A] *Cylinder Number*

Mack T-12
EGR Engine Oil Test
Unscheduled Downtime & Maintenance Summary
Form 11

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

Number of Downtime Occurrences: 9

Test Hours	Date	Downtime	Reasons
56:45	20140929	2:15	Replaced INMAN thermocouple.
86:06	20140930	2:29	Replaced EGR cooler.
96:24	20141001	4:52	Replaced ruptured coolant out hose.
119:19	20141002	0:19	Dynamometer maintenance.
121:22	20141002	0:18	Replaced IMT thermocouple.
163:37	20141004	1:19	Replaced blown coolant hose.
214:02	20141006	2:17	Repaired front oil leak.
225:01	20141006	0:21	Down per project manager.
299:05	20141010	4:53	Repaired boost leak
Total Downtime		019:03	

Other Comments

Number of Comment Lines: 0

Mack T-12
EGR Engine Oil Test
Test Fuel Analysis (Last Batch)
Form 12

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 06:12	
Test Number: 83-108-2M7188-1208		**Oil Code:** LO292039	
Formulation / Stand Code:			
Supplier: PHILLIPS		**Batch Identifiers:** 14HPP1002	

Measurement	Specifications	Analysis		Test Method
		New	EOT	
Total Sulfur, ppm	7 -15	10.20	8.30	D 5453
Gravity, °API	34 - 37	36.5	36.4	D 4052
Hydrocarbon Composition				
Aromatics % wt.	26 - 31.5	28.0		D 5186
Olefin % Vol.	Report	2.4		D 1319
Cetane Index	Report	45.9		D 976
Cetane No.	43 - 47	45.0		D 613
Copper Strip Corrosion	1 Maximum	1		D 130
Flash Point, °C	54 Minimum	63		D 93
Pour Point, °C	-18 Maximum	-27		D 97
Carbon Residue on 10% Residuum, %	0.35 Maximum	0.10		D 524 (10% Bottoms)
Water & Sediment, % Vol	0.05 Maximum	0.00		D 2709
Viscosity, cSt @ 40°C	2.0 - 2.6	2.3		D 445
Total Acid Number	0.05 Maximum	0.01		D 664-1
Strong Acid Number	0.00 Maximum	0.00		D 664-1
Accelerated Stability	1.5 max	0.3		D 2274
Ash, % Wt.	0.005 max	0.000		D 482
SLBOCLE, g	3100 min [A]			D 6078 [A]
90% Distillation, °C	293 - 332	304		D 86

[A] *May be altered to be consistent with CARB or ASTM diesel fuel specifications.*

Mack T-12
EGR Engine Oil Test
Characteristics of the Data Acquisition System
Form 13

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	06:12
Test Number:	83-108-2M7188-1208	**Oil Code:**	LO292039		
Formulation / Stand Code:					

Parameter (1)	Sensing Device (2)	Calibration Frequency (3)	Record Device (4)	Observation Frequency (5)	Record Frequency (6)	Log Frequency (7)	System Response (8)
Temperatures							
Oil @ Filt.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Fuel In.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Intake Air	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Intake Man.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Pre-Turb.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Cool. Out	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Other							
Fuel Flow	Mass Flow	Reference	C/D	0	0	1/6 min.	36.1s
Engine RPM	Magnetic	Reference	C/D	0	0	1/6 min.	2.0s
Load	StrainGage	Reference	C/D	0	0	1/6 min.	0.5s
Inlet Restr.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s
Exh. Press.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s
Oil Gal. Press.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s

Legend:

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
LG - Handlog Sheet
DL - Automatic Data Logger
SC - Strip Chart Recorder
C/M - Computer, Using Manual Data Entry
C/D - Computer, Using Direct I/O Entry
(5) Data is Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data is Logged as Permanent Record, Note Specify if:
SS - Snapshot Taken at Specified Frequency
AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output of Reach 63.2% of Final Valve for Step Change at Input

Mack T-12
EGR Engine Oil Test
Build-up and Hardware Information
Form 14

Laboratory:	SR	EOT Date:	20141010	EOT Time:	06:12
Test Number:	83-108-2M7188-1208	Oil Code:	LO292039		
Formulation / Stand Code:					

Injection Timing	
Timing Hours	**Timing (Deg)**
0	10.80
0	Total Timing Changes

Hardware		
Part	**Part Number**	**Serial Number**
Primary Turbo Charger	697GC5176M7	[redacted]
Secondary Charger	3801847RX	
Cylinder Head (front)	732GB3494M2	Head Set L.S. 20
Cylinder Head (rear)	732GB3494M2	Head Set L.S. 20
Pistons	5125M	[redacted]
Injection Nozzles	736GB419M3	
Rod Bearings	M1062GBT100-X	
Liners	509GC471	
Ring Set	353GC2141	

Cylinder Kit Location	CPD ID Number
Cylinder 1	180919-VUXO
Cylinder 2	180920-VUXO
Cylinder 3	180921-VUXO
Cylinder 4	180922-VUXO
Cylinder 5	180923-VUXO
Cylinder 6	180924-VUXO

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 1
Form 15

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		
Date Rated: 20141013	Rater Initials: RBV	Verified By: MM

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0							6	6.00											
Carbon	MC - 0.5	6	3.00																	
Carbon	LC - .25	94	23.50	100	25.00	75	18.75	89	22.25		5	1.25	70	17.50			90	22.50	15	3.75
Carbon	Total	100	26.50	100	25.00	75	18.75	95	28.25		5	1.25	70	17.50	0	0.00	90	22.50	15	3.75
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	25	0	5	0	Clean	95	0	30	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	25	0.00	5	0.00		95	0.00	30	0.00	100	0.00	0	0.00	0	0.00
Rating		26.50		25.00		18.75		28.25			1.25		17.50		0.00		22.50		3.75	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		53.00		75.00		18.75		84.75			25.00		350.00		0.00		11.25		3.75	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
621.6	26.50	18.75	143.6	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 2
Form 16

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	06:12
Test Number:	83-108-2M7188-1208	**Oil Code:**	LO292039		
Formulation / Stand Code:					
Date Rated:	20141013	**Rater Initials:**	RBV	**Verified By:**	MM

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			4	4.00	10	10.00	2	2.00											
	MC - 0.5																			
	LC - .25	100	25.00	96	24.00	74	18.50	94	23.50				61	15.25			90	22.50	10	2.50
	Total	100	25.00	100	28.00	84	28.50	96	25.50		0	0.00	61	15.25	0	0.00	90	22.50	10	2.50
Varnish	8 - 9																			
	7 - 7.9									7.5										
	6 - 6.9																			
	5 - 5.9																			
	4 - 4.9									4.5										
	3 - 3.9																			
	2 - 2.9																			
	1 - 1.9									1.5										
	>0 - 0.9																			
	Clean		0		0	16	0	4	0	Clean	100	0	39	0	100	0		0		0
	Total	0	0.00	0	0.00	16	0.00	4	0.00		100	0.00	39	0.00	100	0.00	0	0.00	0	0.00
Rating		25.00		28.00		28.50		25.50			0.00		15.25		0.00		22.50		2.50	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		50.00		84.00		28.50		76.50			0.00		305.00		0.00		11.25		2.50	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
557.7	25.00	28.50	147.2	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 3
Form 17

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 06:12	
Test Number: 83-108-2M7188-1208		**Oil Code:** LO292039	
Formulation / Stand Code:			
Date Rated: 20141013	**Rater Initials:** RBV	**Verified By:** MM	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			7	7.00			11	11.00				1	1.00						
	MC - 0.5																			
	LC - .25	100	25.00	93	23.25	78	19.50	84	21.00				30	7.50			90	22.50	20	5.00
	Total	100	25.00	100	30.25	78	19.50	95	32.00		0	0.00	31	8.50	0	0.00	90	22.50	20	5.00
Varnish	8 - 9									7.5										
	7 - 7.9																			
	6 - 6.9																			
	5 - 5.9									4.5										
	4 - 4.9																			
	3 - 3.9																			
	2 - 2.9									1.5										
	1 - 1.9																			
	>0 - 0.9																			
	Clean		0		0	22	0	5	0	Clean	100	0	69	0	100	0		0		0
	Total	0	0.00	0	0.00	22	0.00	5	0.00		100	0.00	69	0.00	100	0.00	0	0.00	0	0.00
Rating		25.00		30.25		19.50		32.00			0.00		8.50		0.00		22.50		5.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		50.00		90.75		19.50		96.00			0.00		170.00		0.00		11.25		5.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
442.6	25.00	19.50	142.7	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 4
Form 18

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 06:12	
Test Number: 83-108-2M7188-1208		**Oil Code:** LO292039	
Formulation / Stand Code:			
Date Rated: 20141013	**Rater Initials:** RBV	**Verified By:** MM	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			1	1.00	2	2.00	5	5.00											
Carbon	MC - 0.5	6	3.00																	
Carbon	LC - .25	94	23.50	99	24.75	95	23.75	88	22.00		6	1.50	45	11.25			85	21.25	10	2.50
Carbon	Total	100	26.50	100	25.75	97	25.75	93	27.00		6	1.50	45	11.25	0	0.00	85	21.25	10	2.50
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	3	0	7	0	Clean	94	0	55	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	3	0.00	7	0.00		94	0.00	55	0.00	100	0.00	0	0.00	0	0.00
Rating		26.50		25.75		25.75		27.00			1.50		11.25		0.00		21.25		2.50	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		53.00		77.25		25.75		81.00			30.00		225.00		0.00		10.62		2.50	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
505.0	26.50	25.75	141.6	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 5
Form 19

Laboratory:	SR	EOT Date:	20141010	EOT Time:	06:12
Test Number:	83-108-2M7188-1208	Oil Code:	LO292039		
Formulation / Stand Code:					
Date Rated:	20141013	Rater Initials:	RBV	Verified By:	MM

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			5	5.00			6	6.00				3	3.00						
Carbon	MC - 0.5																			
Carbon	LC - .25	100	25.00	95	23.75	90	22.50	89	22.25				84	21.00			95	23.75	10	2.50
Carbon	Total	100	25.00	100	28.75	90	22.50	95	28.25		0	0.00	87	24.00	0	0.00	95	23.75	10	2.50
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	10	0	5	0	Clean	100	0	13	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	10	0.00	5	0.00		100	0.00	13	0.00	100	0.00	0	0.00	0	0.00
Rating		25.00		28.75		22.50		28.25			0.00		24.00		0.00		23.75		2.50	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		50.00		86.25		22.50		84.75			0.00		480.00		0.00		11.88		2.50	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
737.8	25.00	22.50	154.7	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 6
Form 20

Laboratory: SR	**EOT Date:** 20141010		**EOT Time:** 06:12
Test Number: 83-108-2M7188-1208		**Oil Code:** LO292039	
Formulation / Stand Code:			
Date Rated: 20141013	**Rater Initials:** RBV		**Verified By:** MM

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
	Dep. Factor	No. 1		No. 2		No. 1		No. 2		Dep. Factor	No. 3		No. 3		No. 4					
		A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.		A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			45	45.00	4	4.00													
Carbon	MC - 0.5	19	9.50																	
Carbon	LC - .25	81	20.25	55	13.75	91	22.75	98	24.50		25	6.25	65	16.25			95	23.75	15	3.75
Carbon	Total	100	29.75	100	58.75	95	26.75	98	24.50		25	6.25	65	16.25	0	0.00	95	23.75	15	3.75
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	5	0	2	0	Clean	75	0	35	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	5	0.00	2	0.00		75	0.00	35	0.00	100	0.00	0	0.00	0	0.00
Rating		29.75		58.75		26.75		24.50			6.25		16.25		0.00		23.75		3.75	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		59.50		176.25		26.75		73.50			125.00		325.00		0.00		11.88		3.75	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
801.8	29.75	26.75	189.7	0

Mack T-12
EGR Engine Oil Test
Main Bearing Weight Loss
Form 21

Laboratory:	SR	EOT Date:	20141010	EOT Time:	06:12
Test Number:	83-108-2M7188-1208	Oil Code:	LO292039		
Formulation / Stand Code:					

Position #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Upper	148.0544	148.0301	24.3
2	Upper	172.1671	172.1278	39.3
3	Upper	172.2493	172.2280	21.3
4	Upper	244.1042	244.0833	20.9
5	Upper	172.2381	172.1984	39.7
6	Upper	172.1817	172.1390	42.7
7	Upper	268.2614	268.2302	31.2
Upper Bearing Average Weight Loss, mg				31.3
Upper Bearing Weight Loss Std. Dev., mg				9.3
Upper Bearing Minimum Weight Loss, mg				20.9
Upper Bearing Maximum Weight Loss, mg				42.7

Position #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Lower	188.1950	188.1743	20.7
2	Lower	187.8870	187.8442	42.8
3	Lower	187.9981	187.9550	43.1
4	Lower	283.2072	283.1793	27.9
5	Lower	188.0454	187.9910	54.4
6	Lower	188.0280	187.9528	75.2
7	Lower	283.3812	283.3610	20.2
Lower Bearing Average Weight Loss, mg				40.6
Lower Bearing Weight Loss Std. Dev., mg				19.9
Lower Bearing Minimum Weight Loss, mg				20.2
Lower Bearing Maximum Weight Loss, mg				75.2

Main Bearing Batch ID	180919-O

Mack T-12
EGR Engine Oil Test
Ring Gap Measurements
Form 22

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

Top Ring Gap. mm			
Cylinder No.	SOT	EOT	Delta (EOT - SOT)
1	0.610	0.610	0.000
2	0.686	0.711	0.025
3	0.610	0.610	0.000
4	0.610	0.635	0.025
5	0.610	0.635	0.025
6	0.610	0.610	0.000
Average			0.013

2nd Ring Gap. mm			
Cylinder No.	SOT	EOT	Delta (EOT - SOT)
1	0.508	0.533	0.025
2	0.432	0.432	0.000
3	0.432	0.457	0.025
4	0.406	0.432	0.026
5	0.432	0.432	0.000
6	0.457	0.457	0.000
Average			0.013

Oil Ring Gap. mm			
Cylinder No.	SOT	EOT	Delta (EOT - SOT)
1	0.533	0.584	0.051
2	0.559	0.610	0.051
3	0.559	0.584	0.025
4	0.508	0.533	0.025
5	0.508	0.533	0.025
6	0.483	0.533	0.050
Average			0.038

Mack T-12
EGR Engine Oil Test
T-10 Merits Calculated with T-12 Results
Form 23

Laboratory: SR	EOT Date: 20141010	EOT Time: 06:12
Test Number: 83-108-2M7188-1208	Oil Code: LO292039	
Formulation / Stand Code:		

	Delta Pb @ EOT (ppm)	Avg. Liner Wear (µm)	Avg, Top Ring Weight Loss (mg)	Oil Consumption (g/h)	Delta Pb 250-300h (ppm)
T-12 Final Original Unit Result	20	25.4	45	64.4	7
T-10 Mack Merits [A]	320.0	50.0	400.0	232.5	292.3
Total T-10 Mack Merits [A]	1294.8				

[A] *Non-reference Tests only.*

Mack T-12
EGR Engine Oil Test

Version 20100308

Title / Validity Declaration Page

Form 1

Conducted for

SOUTHWEST RESEARCH INSTITUTE

V	V = Valid; The Reference Oil/Non Reference Oil was Evaluated in Accordance with the Test Procedure.
	I = Invalid; The Reference Oil/Non-Reference Oil was not Evaluated in Accordance with the Test Procedure.
	N = Results cannot be Interpreted as Representative of Oil Performance (Non-Reference Oil) and shall not be used in Determining an Average Test Result using Multiple Test Criteria

NR	NR = Non Reference Oil Test
	RO = Reference Oil Test

Stand: 94	**Stand Run No.:** 7	**Engine No.:** 2M6349	**Engine Hours:** 1300
End of Test Date: 20141010		**End of Test Time:** 03:48	
Oil Code / CMIR:[A] LO306520			
Formulation / Stand Code:[B]			
Altcode1:[C]	**Altcode2:**[C]	**Altcode3:**[C]	

In my opinion this test has been conducted in a valid manner in accordance with the Test Method D7422 and the appropriate amendments through the information letter system. The remarks included in this report the anomalies associated with this test.

[A] *CMIR or Non-Reference Oil Code*

[B] *ACC-Registered Tests Only*

[C] *When Provided or Required by Client*

Submitted by: **Southwest Research Institute (R)**
Testing Laboratory

Robert Warden
Signature

Robert W. Warden
Typed Name

Research Engineer
Title

Mack T-12
EGR Engine Oil Test
Table of Contents
Form 2

Laboratory:	SR	EOT Date:	20141010	EOT Time:	03:48
Test Number:	94-7-2M6349-1300	Oil Code:	LO306520		
Formulation / Stand Code:					

[A] *ACC-Registered Tests Only*

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

The Mack T-12 EGR Engine Oil Test is a fuel engine-dynamometer test which evaluates the ability of a lubricant to minimize piston ring wear, cylinder liner wear, and lead corrosion, oil consumption, and oxidation. This test is a two-phase, steady state test (constant speed and load), run with heavy EGR. The first phase is 100 hours and is run with retarded fuel injection timing to produce elevated soot levels in the oil. The second phase is 200 hours and is run under heavy load conditions to induce piston ring and cylinder liner wear.

The test engine is a Mack E-TECH V-MAC III diesel engine with EGR. It is an in-line six cylinder, four-stroke, turbocharged engine. It has electronically controlled fuel injection with six individual electronic unit pumps. A one hour break-in is conducted prior to each test since a new engine build is used for each test.

Mack T-12 Test Conditions

Parameter	Phase I	Phase II
Time, h	100	200
Injection Timing, °BTDC	Variable	21
Speed, r/min	1800	1200
Fuel Flow, kg/h	59.2	63.5
Intake CO_2, %	3.09	1.42
Exhaust CO_2, %	9.25	9.78-10.08 typical
Inlet Manifold Temp., °C	90	80
Coolant Out Temp., °C	66	108
Fuel In Temp., °C	40	40
Oil Gallery Temp., °C	88	116
Intake Air Temp., °C	25	25
Intake Air Restriction, kPa	3.5 - 4.0	3.5 - 4.0
Inlet Manifold Pressure, kPa	265 Nominal	302-312
Exhaust Back Pressure, kPa	2.7 - 3.5	2.7 - 3.5
Crankcase Pressure, kPa	0.25 - 0.75	0.25 - 0.75
Power, kW	Record	Record
Torque, Nm	Record	Record
Pre-Turbine Exhaust Temp., °C	Record	Record
Tailpipe Exhaust Temp., °C	Record	Record
Oil Sump Temp., °C	Record	Record
EGR Pre-Venturi Temp., °C	Record	Record
Inlet Air Dew Point, °C	Record	Record
Inlet Air Humidity, kg/kg	Record	Record
Main Gallery Oil Pressure, kPa	Record	Record
Oil Filter Delta P, kPa	Not to exceed 138	Not to exceed 138

Mack T-12
EGR Engine Oil Test
Test Results Summary
Form 4

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

Test Results

Date Test Started:	20140926	Start Time:	15:27	Test Length:	300
TMC Oil Code: [A]		Laboratory Oil Code:	LO-306520	SAE Viscosity:	N/A
Average TGA Soot % at 100 h	4.0				
Centrifugal Oil Filter Mass Gain, g	240.4				
Oil Filter Delta P, kPa (138 maximum)	4				
EOT TBN	2.7				

[redacted]	Delta Pb @ EOT (ppm)	Avg. Liner Wear (μm)	Avg. Top Ring Weight Loss (mg)	Oil Consumption (g/h)	Delta Pb 250-300h (ppm)
Original Result	90	57.4	116	119.6	34
Transformed Result [B]	4.4998	57.4000	116.0000	4.7842	3.5264
Correction Factor [B]	0.8130	0.8180	0.7190	0.9130	0.7100
Corrected Transformed Result [B]	3.6583	46.9532	83.4040	4.3680	2.5037
Severity Adjustment [B]	0.0000	1.1294	0.0000	-0.0496	0.0000
Final Transformed Result [B]	3.6583	48.0826	83.4040	4.3184	2.5037
Final Original Unit Result	39	48.1	83	75.1	12
Mack Merits [C]	-80.0	-1506.2	125.7	74.3	120.0
Total Mack Merits: [C]	-1266.2				

Last Stand Reference Results

Test Number:	94-1-1MKSLA-0		
Oil Code:	CMIR-98461 SR-109		
Test Length:	300	TMC Oil Code: [A]	821-3
EOT Date:	20140224	EOT Time:	07:52
Number of Tests Since Stand Calibration: [D]	5		
Stand Calibration Expiration Date:	20141224		
Average TGA Soot % at 100 h:	4.1		

[redacted]	Delta Pb @ EOT (ppm)	Avg. Liner Wear (μm)	Avg. Top Ring Weight Loss (mg)	Oil Consumption (g/h)	Delta Pb 250-300h (ppm)
Final Original Unit Result	22	13.1	82	59.0	9

A Reference Tests Only

B Transformed Units apply to Delta Pb, @ EOT, Oil Consumption, and Delta 250-300 h only.

C Non-Reference Tests Only

D Operationally valid tests only, including current test.

Mack T-12
EGR Engine Oil Test
Operational Summary
Form 5

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

	Parameter	Units	QI Threshold	EOT QI[A]	Target		Average		Samples[B]	BQD[C]	Over/Under Range[D]
Controlled Parameters	Speed	r/min	0.000	0.988	1800	1200	1800	1200	3000	0	0
	Fuel Flow	kg/h	0.000	0.994	59.2	63.5	59.18	63.50	3000	0	0
	Inlet Manifold Temp.	°C	0.000	0.767	90	80	90	80	3000	0	0
	Coolant Out Temp.	°C	0.000	0.937	66	108	66	108	3000	0	0
	Fuel In Temp.	°C	0.000	0.328	40		40		3000	0	0
	Oil Gallery Temp.	°C	0.000	0.791	88	116	88	116	3000	0	0
	Intake Air Temp.	°C	0.000	0.774	25		25		3000	0	0
	Inlet Air Restriction	kPa			3.5 - 4.0		3.73		3000	0	0
	Inlet Man. Pressure	kPa			265 Nominal	307 ± 5	266	306	3000	0	0
	Exh. Back Pressure	kPa			2.7 - 3.5		3.1		3000	0	0
	Crankcase Pressure	kPa			0.25 - 0.75		0.56		3000	0	0
	Intake CO_2	%			3.09 ± .05	1.42 ± .05	3.07	1.40			
	Exhaust CO_2	%			9.25 ± .15	9.93 ± .15	9.15	10.07			

	Parameter	Units	Typical Values[E]		Average	
Non-controlled Parameters	Torque	Nm	1232-1397	2434-2543	1349	2505
	Brake Specific Fuel Cons.	g/kW-h	212-263	179-228	232.7	201.7
	Pre-Turbine Temp. (L)	°C	482-605	504-759	539	650
	Pre-Turbine Temp. (R)	°C	503-567	491-758	532	623
	Tailpipe Temp.	°C	303-354	280-433	324	399
	Oil Sump Temp.	°C	92-105	73-190	98	129
	EGR Pre-Venturi Temp.	°C	138-201	107-126	163	121
	Blowby	L/min	41-176	71-264	73.6	158.6
	Inlet Air Dew Point	°C	6-22	6-22	22	21
	EGR Pre-Venturi Pressure	kPa	226-331	235-336	91	155
	Main Gallery Oil Pressure	kPa	394-502	165-269	357	161

A QI values above the threshold are acceptable by the Mack Surveillance Panel. QI values below the threshold may not be considered acceptable based on an engineering review. Refer to Annex A5.

B Total number of data points taken. Minimum acceptable value is 3000.

C Number of Bad Quality Data points not used in the calculation of the statistical measures.

D Number of points clipped by over/under range limits.

Mack T-12
EGR Engine Oil Test
Rod Bearing Weight Loss
Form 6

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48	
Test Number: 94-7-2M6349-1300		**Oil Code:** LO306520	
Formulation / Stand Code:			

Cylinder #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Upper	98.6590	97.8700	789.0
2	Upper	98.2926	97.0206	1272.0
3	Upper	98.5436	98.2064	337.2
4	Upper	98.4494	98.1388	310.6
5	Upper	98.6256	97.7659	859.7
6	Upper	98.4306	97.6636	767.0

Summary	As Measured	Outlier Screened
Upper Bearing Average Weight Loss, mg	722.6	722.6
Upper Bearing Weight Loss Std. Dev., mg	359.2	359.2
Upper Bearing Minimum Weight Loss, mg	310.6	310.6
Upper Bearing Maximum Weight Loss, mg	1272.0	1272.0
Outlier Upper Rod Bearing [A]	N	

[A] *Cylinder number*

Cylinder #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Lower	98.0288	97.9787	50.1
2	Lower	97.9326	97.8421	90.5
3	Lower	98.0906	98.0807	9.9
4	Lower	98.0001	97.9956	4.5
5	Lower	98.1392	98.0922	47.0
6	Lower	97.9827	97.9450	37.7
Lower Bearing Average Weight Loss, mg				39.9
Lower Bearing Weight Loss Std. Dev., mg				31.2
Lower Bearing Minimum Weight Loss, mg				4.5
Lower Bearing Maximum Weight Loss, mg				90.5

Conrod Bearing Batch ID	X

Mack T-12
EGR Engine Oil Test
Ring Weight Loss
Form 7

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		

Cylinder No.	Top Ring SOT Weight, g	Top Ring EOT Weight, g	Weight Loss, mg
1	31.3402	31.1718	168.4
2	31.3424	31.1585	183.9
3	31.3493	31.2635	85.8
4	31.3669	31.2479	119.0
5	31.2336	31.1523	81.3
6	31.3403	31.2848	55.5

Summary	As Measured [A]	Outlier Screened
Top Ring Average Weight Loss, mg	116	116
Top Ring Weight Loss Std. Dev., mg	51.3	51.3
Top Ring Minimum Weight Loss, mg	55.5	55.5
Top Ring Maximum Weight Loss, mg	183.9	183.9
Outlier Ring [B]	N	

[A] *Results calculated without rings with plasma flaking.*

[B] *Ring number wear results are not currently outlier screened.*

Cylinder No.	2nd Ring SOT Weight, g	2nd Ring EOT Weight, g	Weight Loss, mg
1	27.2143	27.1753	39.0
2	27.1651	27.1359	29.2
3	27.2745	27.2473	27.2
4	27.1733	27.1451	28.2
5	27.2960	27.2561	39.9
6	27.3570	27.3300	27.0
		2nd Ring Average Weight Loss, mg	31.8
		2nd Ring Weight Loss Std. Dev.,mg	6.0
		2nd Ring Min. Weight Loss, mg	27.0
		2nd Ring Max. Weight Loss, mg	39.9

Cylinder No.	Oil Ring SOT Weight, g	Oil Ring EOT Weight, g	Weight Loss, mg
1	37.0838	37.0511	32.7
2	36.3725	36.3452	27.3
3	36.8838	36.8574	26.4
4	36.8456	36.8159	29.7
5	36.8308	36.7999	30.9
6	36.5229	36.4957	27.2
		Oil Ring Average Weight Loss, mg	29.0
		Oil Ring Weight Loss Std. Dev.,mg	2.5
		Oil Ring Min. Weight Loss, mg	26.4
		Oil Ring Max. Weight Loss, mg	32.7

Mack T-12
EGR Engine Oil Test
Oil Analysis Summary
Form 8

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		

Hours	Soot Wt. % TGA	Viscosity at 100°C cSt	Viscosity Increase cSt	TBN	TAN	IR Oxidation Integrated	IR Oxidation Peak Height	Metals Elements (ppm) Fe	Pb	Cu	Cr	Al	Si	Sn	Na	Ni
000	0.2	8.92	[redacted]	10.3	2.9	0.0	0.0	2	<1	<1	<1	4	5	<1	21	<1
025	0.9	9.68	0.76	9.7	3.4	-210.9	0.5	18	3	5	<1	4	11	1	25	1
050	1.6	9.97	1.05	9.4	3.2	-249.7	3.2	33	4	7	2	4	14	1	28	3
075	2.7	10.49	1.57	8.4	3.3	-290.6	5.4	47	4	9	2	4	16	2	29	3
100	4.0	10.99	2.07	7.9	3.0	-367.9	7.2	69	4	11	4	4	19	2	30	4
100 (2nd)	4.0	[redacted]														
100 Avg.	4.0															
125	4.3	10.84	1.92	6.0	3.2	-421.3	10.8	146	6	20	5	4	23	4	32	6
150	4.7	11.22	2.30	4.6	3.4	-561.3	14.8	207	8	43	7	5	26	5	38	6
175	4.9	11.65	2.73	4.2	3.3	-569.5	17.6	240	5	34	7	5	28	5	38	6
200	5.1	12.20	3.28	3.5	3.8	-653.5	19.4	306	19	40	8	5	31	6	43	7
250	5.5	13.13	4.21	3.2	4.2	-569.1	24.2	434	57	51	9	6	36	9	45	8
275	5.5	13.47	4.55	3.2	4.5	-526.8	26.4	452	65	52	9	6	34	9	44	8
300	6.0	14.45	5.53	2.7	5.0	-381.7	32.4	560	91	62	13	6	44	11	46	13

Summary	As Measured	Outlier Bearing
Delta Pb @ EOT, ppm	90	90
Delta Pb 250-300 h, ppm	34	[redacted]
MRV Yield Stress, Pa	0	

MRV @ 100h, cP	1800
MRV @ 100h with Severity Adjustment, cP	3068

Mack T-12
EGR Engine Oil Test
Liner Surface Roughness & Bore Diameter
Form 9

Laboratory: SR	**EOT Date:** 20141010		**EOT Time:** 03:48
Test Number: 94-7-2M6349-1300		**Oil Code:** LO306520	
Formulation / Stand Code:			

Liner No.	Location	Ra (μm)	Bore Diameter (mm)		Ra (μm)	Dia. (mm)
1	Top Ring Travel @ 0°	17.80	123.848	Avg	18.02	123.850
	Top Ring Travel @ 90°	18.20	123.853	Std Dev	0.17	
	Top Ring Travel @ 180°	18.00		Min	17.80	
	Top Ring Travel @ 270°	18.10		Max	18.20	
2	Top Ring Travel @ 0°	17.70	123.858	Avg	17.60	123.865
	Top Ring Travel @ 90°	18.20	123.873	Std Dev	0.70	
	Top Ring Travel @ 180°	17.90		Min	16.60	
	Top Ring Travel @ 270°	16.60		Max	18.20	
3	Top Ring Travel @ 0°	17.10	123.855	Avg	16.85	123.867
	Top Ring Travel @ 90°	16.30	123.878	Std Dev	0.49	
	Top Ring Travel @ 180°	16.60		Min	16.30	
	Top Ring Travel @ 270°	17.40		Max	17.40	
4	Top Ring Travel @ 0°	17.10	123.866	Avg	17.02	123.876
	Top Ring Travel @ 90°	16.80	123.886	Std Dev	0.22	
	Top Ring Travel @ 180°	17.30		Min	16.80	
	Top Ring Travel @ 270°	16.90		Max	17.30	
5	Top Ring Travel @ 0°	16.40	123.866	Avg	17.45	123.876
	Top Ring Travel @ 90°	18.50	123.886	Std Dev	1.16	
	Top Ring Travel @ 180°	18.40		Min	16.40	
	Top Ring Travel @ 270°	16.50		Max	18.50	
6	Top Ring Travel @ 0°	16.70	123.863	Avg	17.00	123.874
	Top Ring Travel @ 90°	17.40	123.886	Std Dev	0.41	
	Top Ring Travel @ 180°	17.30		Min	16.60	
	Top Ring Travel @ 270°	16.60		Max	17.40	

	Ra (μm)	Bore Diameter (mm)
Average Surface Roughness & Bore Diameter	17.32	123.868
Standard Deviation Surface Roughness & Bore Diameter	0.45	0.010
Minimum Surface Roughness & Bore Diameter	16.85	123.850
Maximum Surface Roughness & Bore Diameter	18.02	123.876

Mack T-12
EGR Engine Oil Test
Liner Wear Summary
Form 10

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48
Test Number: 94-7-2M6349-1300	**Oil Code:** LO306520	
Formulation / Stand Code:		

Position	**Wear Step (μm)**					
	Cylinder Number					
	1	**2**	**3**	**4**	**5**	**6**
1:00	57.1	53.4	64.0	83.8	108.3	86.5
2:00	68.9	39.0	67.2	84.2	117.4	75.9
3:00 (Thrust)	78.4	33.9	55.7	71.5	125.0	86.2
4:00	40.1	44.7	47.5	75.3	92.2	79.8
5:00	27.3	40.2	58.1	49.1	67.5	68.2
6:00 (Rear)	24.1	30.7	55.0	24.2	56.0	36.9
7:00	25.3	25.7	54.5	29.5	61.3	40.7
8:00	63.0	28.1	57.7	49.8	79.3	40.8
9:00 (Anti-Thrust)	75.9	24.1	69.2	53.0	79.7	50.9
10:00	68.3	20.2	69.0	49.3	92.8	54.6
11:00	38.4	22.3	57.8	32.1	82.8	54.1
12:00 (Front)	60.7	27.5	50.8	34.0	86.2	51.5
Average	52.3	32.5	58.9	53.0	87.4	60.5

Summary	**As Measured**	**Outlier Screened**
Average, μm	57.4	57.4
Std. Dev., μm	17.8	17.8
Minimum, μm	32.5	32.5
Maximum, μm	87.4	87.4
Outlier Liners [A]	N	

[A] *Cylinder Number*

Mack T-12
EGR Engine Oil Test
Unscheduled Downtime & Maintenance Summary
Form 11

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

Number of Downtime Occurrences: 7

Test Hours	Date	Downtime	Reasons
10:00	20140927	1:52	Repaired coolant leak at EGR hose: Restart
31:30	20140928	0:16	Tripped T-Safety: Restart
38:00	20140928	7:39	Repaired coolant leak at oil cooler: Restart
75:00	20140930	2:33	Repaired fuel injector leak: Restart
124:05	20141002	1:17	Tower water maintenance: Restart
131:52	20141002	0:16	Repaired fuel leak at fuel rail line: Restart
285:47	20141009	10:19	Repaired turbo leak: Restart
31:30	20140928	0:16	TSAFETY was 0.3 min = 0.5
38:00	20140928	7:39	Stop button pressed.
75:00	20140930	2:33	Stop button pressed.
124:05	20141002	1:17	Stop button pressed.
131:52	20141002	0:16	Stop button pressed.
285:47	20141009	10:19	Stop button pressed.
Total Downtime		024:12	

Other Comments

Number of Comment Lines: 1

Engine to idle for samples due to safety.

Mack T-12
EGR Engine Oil Test
Test Fuel Analysis (Last Batch)
Form 12

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		
Supplier: PHILLIPS	Batch Identifiers: 14DPP1001	

Measurement	Specifications	Analysis		Test Method
		New	EOT	
Total Sulfur, ppm	7 -15	11.90	9.20	D 5453
Gravity, °API	34 - 37	37.7	36.4	D 4052
Hydrocarbon Composition				
Aromatics % wt.	26 - 31.5	31.5		D 5186
Olefin % Vol.	Report	4.3		D 1319
Cetane Index	Report	46.2		D 976
Cetane No.	43 - 47	45.0		D 613
Copper Strip Corrosion	1 Maximum	1		D 130
Flash Point, °C	54 Minimum	69		D 93
Pour Point, °C	-18 Maximum	-40		D 97
Carbon Residue on 10% Residuum, %	0.35 Maximum	0.10		D 524 (10% Bottoms)
Water & Sediment, % Vol	0.05 Maximum	0.00		D 2709
Viscosity, cSt @ 40°C	2.0 - 2.6	2.3		D 445
Total Acid Number	0.05 Maximum	0.01		D 664-1
Strong Acid Number	0.00 Maximum	0.00		D 664-1
Accelerated Stability	1.5 max	0.2		D 2274
Ash, % Wt.	0.005 max	0.000		D 482
SLBOCLE, g	3100 min [A]			D 6078 [A]
90% Distillation, °C	293 - 332	299		D 86

[A] *May be altered to be consistent with CARB or ASTM diesel fuel specifications.*

Mack T-12
EGR Engine Oil Test
Characteristics of the Data Acquisition System
Form 13

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		

Parameter (1)	Sensing Device (2)	Calibration Frequency (3)	Record Device (4)	Observation Frequency (5)	Record Frequency (6)	Log Frequency (7)	System Response (8)
Temperatures							
Oil @ Filt.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Fuel In.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Intake Air	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Intake Man.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Pre-Turb.	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Cool. Out	T/C	Reference	C/D	0	0	1/6 min.	3.0s
Other							
Fuel Flow	Mass Flow	Reference	C/D	0	0	1/6 min.	36.1s
Engine RPM	Magnetic	Reference	C/D	0	0	1/6 min.	2.0s
Load	StrainGage	Reference	C/D	0	0	1/6 min.	0.5s
Inlet Restr.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s
Exh. Press.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s
Oil Gal. Press.	Transducer	Reference	C/D	0	0	1/6 min.	3.0s

Legend:

(1) Operating Parameter
(2) The Type of Device Used to Measure Temperature, Pressure or Flow
(3) Frequency at Which the Measurement System is Calibrated
(4) The Type of Device Where Data is Recorded
LG - Handlog Sheet
DL - Automatic Data Logger
SC - Strip Chart Recorder
C/M - Computer, Using Manual Data Entry
C/D - Computer, Using Direct I/O Entry
(5) Data is Observed but Only if Recorded Off Spec.
(6) Data are Recorded but are not Retained at EOT
(7) Data is Logged as Permanent Record, Note Specify if:
SS - Snapshot Taken at Specified Frequency
AG/X Average of X Data Points at Specified Frequency
(8) Time for the Output of Reach 63.2% of Final Valve for Step Change at Input

Mack T-12
EGR Engine Oil Test
Build-up and Hardware Information
Form 14

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

Injection Timing	
Timing Hours	**Timing (Deg)**
0	10.80
22	10.20
44	9.30
55	7.50
63	6.60
99	6.90
5	Total Timing Changes

Hardware		
Part	**Part Number**	**Serial Number**
Primary Turbo Charger	631GC5176M7	[redacted]
Secondary Charger	3801647RX	[redacted]
Cylinder Head (front)	732GB3499M	Head Set C-015
Cylinder Head (rear)	732GB3499M	Head Set C-015
Pistons	5125M	[redacted]
Injection Nozzles	736GB419M3	[redacted]
Rod Bearings	M1062GBT100	[redacted]
Liners	509GC471	[redacted]
Ring Set	353GC2141	[redacted]

Cylinder Kit Location	**CPD ID Number**
Cylinder 1	180901-VUXO
Cylinder 2	180902-VUXO
Cylinder 3	180903-VUXO
Cylinder 4	180904-VUXO
Cylinder 5	180905-VUXO
Cylinder 6	180906-VUXO

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 1
Form 15

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					
Date Rated:		**Rater Initials:**		**Verified By:**	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			6	6.00	3	3.00	15	15.00											
	MC - 0.5	2	1.00																	
	LC - .25	98	24.50	94	23.50	85	21.25	82	20.50				83	20.75			95	23.75	90	22.50
	Total	100	25.50	100	29.50	88	24.25	97	35.50		0	0.00	83	20.75	0	0.00	95	23.75	90	22.50
Varnish	8 - 9									7.5										
	7 - 7.9																			
	6 - 6.9																			
	5 - 5.9									4.5										
	4 - 4.9																			
	3 - 3.9																			
	2 - 2.9									1.5										
	1 - 1.9																			
	>0 - 0.9																			
	Clean		0		0	12	0	3	0	Clean	100	0	17	0	100	0		0		0
	Total	0	0.00	0	0.00	12	0.00	3	0.00		100	0.00	17	0.00	100	0.00	0	0.00	0	0.00
Rating		25.50		29.50		24.25		35.50			0.00		20.75		0.00		23.75		22.50	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		51.00		88.50		24.25		106.50			0.00		415.00		0.00		11.88		22.50	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
719.7	25.50	24.25	181.7	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 2
Form 16

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48	
Test Number: 94-7-2M6349-1300		**Oil Code:** LO306520	
Formulation / Stand Code:			
Date Rated:	**Rater Initials:**	**Verified By:**	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0			2	2.00	3	3.00	4	4.00				3	3.00						
	MC - 0.5	3	1.50																	
	LC - .25	97	24.25	98	24.50	89	22.25	87	21.75				83	20.75			95	23.75	100	25.00
	Total	100	25.75	100	26.50	92	25.25	91	25.75		0	0.00	86	23.75	0	0.00	95	23.75	100	25.00
Varnish	8 - 9																			
	7 - 7.9									7.5										
	6 - 6.9																			
	5 - 5.9																			
	4 - 4.9									4.5										
	3 - 3.9																			
	2 - 2.9																			
	1 - 1.9									1.5										
	>0 - 0.9																			
	Clean		0		0	8	0	9	0	Clean	100	0	14	0	100	0		0		0
	Total	0	0.00	0	0.00	8	0.00	9	0.00		100	0.00	14	0.00	100	0.00	0	0.00	0	0.00
Rating		25.75		26.50		25.25		25.75			0.00		23.75		0.00		23.75		25.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		51.50		79.50		25.25		77.25			0.00		475.00		0.00		11.88		25.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
745.3	25.75	25.25	175.8	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 3
Form 17

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48	
Test Number: 94-7-2M6349-1300		**Oil Code:** LO306520	
Formulation / Stand Code:			
Date Rated:	**Rater Initials:**	**Verified By:**	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0	6	6.00	15	15.00	5	5.00	11	11.00				2	2.00						
Carbon	MC - 0.5	14	7.00																	
Carbon	LC - .25	80	20.00	85	21.25	84	21.00	83	20.75				83	20.75			95	23.75	100	25.00
Carbon	Total	100	33.00	100	36.25	89	26.00	94	31.75		0	0.00	85	22.75	0	0.00	95	23.75	100	25.00
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	11	0	6	0	Clean	100	0	15	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	11	0.00	6	0.00		100	0.00	15	0.00	100	0.00	0	0.00	0	0.00
Rating		33.00		36.25		26.00		31.75			0.00		22.75		0.00		23.75		25.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		66.00		108.75		26.00		95.25			0.00		455.00		0.00		11.88		25.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
788.0	33.00	26.00	198.6	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 4
Form 18

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48	
Test Number: 94-7-2M6349-1300	**Oil Code:** LO306520		
Formulation / Stand Code:			
Date Rated:	**Rater Initials:**	**Verified By:**	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0	2	2.00			7	7.00	8	8.00				1	1.00						
	MC - 0.5																			
	LC - .25	98	24.50	100	25.00	88	22.00	86	21.50				86	21.50			95	23.75	100	25.00
	Total	100	26.50	100	25.00	95	29.00	94	29.50		0	0.00	87	22.50	0	0.00	95	23.75	100	25.00
Varnish	8 - 9									7.5										
	7 - 7.9																			
	6 - 6.9																			
	5 - 5.9									4.5										
	4 - 4.9																			
	3 - 3.9																			
	2 - 2.9									1.5										
	1 - 1.9																			
	>0 - 0.9																			
	Clean		0		0	5	0	6	0	Clean	100	0	13	0	100	0		0		0
	Total	0	0.00	0	0.00	5	0.00	6	0.00		100	0.00	13	0.00	100	0.00	0	0.00	0	0.00
Rating		26.50		25.00		29.00		29.50			0.00		22.50		0.00		23.75		25.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		53.00		75.00		29.00		88.50			0.00		450.00		0.00		11.88		25.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
732.4	26.50	29.00	181.2	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 5
Form 19

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		
Date Rated:	Rater Initials:	Verified By:

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands				Oil Cooling		Under Crown	
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4					
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0	2	2.00	7	7.00	9	9.00	14	14.00											
Carbon	MC - 0.5	3	1.50																	
Carbon	LC - .25	95	23.75	93	23.25	81	20.25	80	20.00				91	22.75			95	23.75	100	25.00
Carbon	Total	100	27.25	100	30.25	90	29.25	94	34.00		0	0.00	91	22.75	0	0.00	95	23.75	100	25.00
Varnish	8 - 9									7.5										
Varnish	7 - 7.9																			
Varnish	6 - 6.9																			
Varnish	5 - 5.9									4.5										
Varnish	4 - 4.9																			
Varnish	3 - 3.9																			
Varnish	2 - 2.9									1.5										
Varnish	1 - 1.9																			
Varnish	>0 - 0.9																			
Varnish	Clean		0		0	10	0	6	0	Clean	100	0	9	0	100	0		0		0
Varnish	Total	0	0.00	0	0.00	10	0.00	6	0.00		100	0.00	9	0.00	100	0.00	0	0.00	0	0.00
Rating		27.25		30.25		29.25		34.00			0.00		22.75		0.00		23.75		25.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		54.50		90.75		29.25		102.00			0.00		455.00		0.00		11.88		25.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
768.3	27.25	29.25	192.3	0

Mack T-12
EGR Engine Oil Test
Rating Summary: Piston No. 6
Form 20

Laboratory: SR	**EOT Date:** 20141010	**EOT Time:** 03:48	
Test Number: 94-7-2M6349-1300		**Oil Code:** LO306520	
Formulation / Stand Code:			
Date Rated:	**Rater Initials:**	**Verified By:**	

Total Piston Ratings Summary

		Grooves				Lands					Groove		Lands							
		No. 1		No. 2		No. 1		No. 2			No. 3		No. 3		No. 4		Oil Cooling		Under Crown	
	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	Dep. Factor	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.	A,%	Dem.
Carbon	HC - 1.0	10	10.00	5	5.00	9	9.00	18	18.00				1	1.00						
	MC - 0.5	2	1.00																	
	LC - .25	88	22.00	95	23.75	80	20.00	76	19.00				88	22.00			95	23.75	100	25.00
	Total	100	33.00	100	28.75	89	29.00	94	37.00		0	0.00	89	23.00	0	0.00	95	23.75	100	25.00
Varnish	8 - 9																			
	7 - 7.9									7.5										
	6 - 6.9																			
	5 - 5.9																			
	4 - 4.9									4.5										
	3 - 3.9																			
	2 - 2.9																			
	1 - 1.9									1.5										
	>0 - 0.9																			
	Clean		0		0	11	0	6	0	Clean	100	0	11	0	100	0		0		0
	Total	0	0.00	0	0.00	11	0.00	6	0.00		100	0.00	11	0.00	100	0.00	0	0.00	0	0.00
Rating		33.00		28.75		29.00		37.00			0.00		23.00		0.00		23.75		25.00	
Location Factor		2		3		1		3			20		20		60		0.5		1	
Industry Rating		66.00		86.25		29.00		111.00			0.00		460.00		0.00		11.88		25.00	

WDP	TGC	TLC	Unweighted Deposits	T.L. Flaked Carbon %
789.1	33.00	29.00	199.6	1

Mack T-12
EGR Engine Oil Test
Main Bearing Weight Loss
Form 21

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		

Position #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Upper	147.6671		
2	Upper	171.5255		
3	Upper	171.2914		
4	Upper	244.5968		
5	Upper	171.2263		
6	Upper	171.1923		
7	Upper	268.1681		
Upper Bearing Average Weight Loss, mg				
Upper Bearing Weight Loss Std. Dev., mg				
Upper Bearing Minimum Weight Loss, mg				
Upper Bearing Maximum Weight Loss, mg				

Position #	Location	SOT Weight, g	EOT Weight, g	Weight Change, mg
1	Lower	188.0574		
2	Lower	187.9223		
3	Lower	188.0254		
4	Lower	282.2368		
5	Lower	188.1372		
6	Lower	188.0453		
7	Lower	282.0187		
Lower Bearing Average Weight Loss, mg				
Lower Bearing Weight Loss Std. Dev., mg				
Lower Bearing Minimum Weight Loss, mg				
Lower Bearing Maximum Weight Loss, mg				

Main Bearing Batch ID	O

Mack T-12
EGR Engine Oil Test
Ring Gap Measurements
Form 22

Laboratory: SR	EOT Date: 20141010	EOT Time: 03:48
Test Number: 94-7-2M6349-1300	Oil Code: LO306520	
Formulation / Stand Code:		

Top Ring Gap. mm			
Cylinder No.	**SOT**	**EOT**	**Delta (EOT - SOT)**
1	0.610	0.610	0.000
2	0.635	0.660	0.025
3	0.635	0.635	0.000
4	0.610	0.610	0.000
5	0.660	0.660	0.000
6	0.610	0.635	0.025
Average			0.008

2nd Ring Gap. mm			
Cylinder No.	**SOT**	**EOT**	**Delta (EOT - SOT)**
1	0.432	0.457	0.025
2	0.457	0.483	0.026
3	0.432	0.457	0.025
4	0.432	0.457	0.025
5	0.432	0.432	0.000
6	0.457	0.483	0.026
Average			0.021

Oil Ring Gap. mm			
Cylinder No.	**SOT**	**EOT**	**Delta (EOT - SOT)**
1	0.508	0.533	0.025
2	0.508	0.559	0.051
3	0.483	0.533	0.050
4	0.559	0.610	0.051
5	0.559	0.610	0.051
6	0.559	0.584	0.025
Average			0.042

Mack T-12
EGR Engine Oil Test
T-10 Merits Calculated with T-12 Results
Form 23

Laboratory:	SR	**EOT Date:**	20141010	**EOT Time:**	03:48
Test Number:	94-7-2M6349-1300	**Oil Code:**	LO306520		
Formulation / Stand Code:					

	Delta Pb @ EOT (ppm)	Avg. Liner Wear (μm)	Avg, Top Ring Weight Loss (mg)	Oil Consumption (g/h)	Delta Pb 250-300h (ppm)
T-12 Final Original Unit Result	39	48.1	83		12
T-10 Mack Merits [A]	85.7	-1841.7	194.3		215.4
Total T-10 Mack Merits [A]	-1346.3				

[A] *Non-reference Tests only.*